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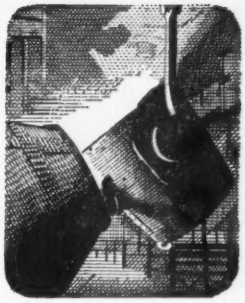

Tonnage Oxygen

THE FIELD OF APPLICATION IN STEELMAKING

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SYNOPSIS

In recent years there has been an increasing interest in the use and application of oxygen for steelmaking in the U.K. The paper provides a general review of the improvements in output obtainable in the melting shop by the use of tonnage oxygen.

An outline is also provided of the comparative operating costs between the classical open-hearth shop, with and without oxygen, and a combination of oxygen application in the open-hearth and oxygen–steam-blown basic Bessemer converter.

Developments in the design and construction of tonnage plants are reviewed and data provided of the plants now in operation or under construction. 1411

Introduction

SINCE THE WAR the Continent of Europe has seen the installation of a number of tonnage oxygen plants supplying large volumes of oxygen for metallurgical purposes. The scale of application in the U.K. has not been so great. At present there are two 100-tons/day plants in operation and a further 900 tons/day of capacity is under construction. It might be concluded from this that development in the U.K. has lagged behind the European countries. This is not necessarily true, as the situation must be reviewed in relation to the economic needs of the respective countries, the existing steelmaking facilities, and the raw-materials situation.

An examination clearly shows that steelmakers had long been aware that one of the widely practised methods of steelmaking on the Continent was not capable of producing steel of sufficiently high quality for certain purposes, which would compete with steel from open-hearth furnaces. Therefore, if the inherent advantages of this method were to be exploited, changes would be necessary in the techniques, without fundamental alterations, which might result in higher capital investment costs or radical alteration to the economic basis of the steelmaking practice.

It has been the practice in many Continental steelworks to operate basic Bessemer (Thomas) converters in conjunction with basic open-hearth furnaces. This policy has been dictated partly by raw materials and partly by fuel supplies. In the early days open-hearth furnaces were operated entirely on producer gas but, as steel output increased, supplies of suitable coal became inadequate to provide the quantity of gas required. As a result, the basic Bessemer process found favour since, after the blast-furnace, no additional fuel is required to complete the steelmaking operation, the energy for the converter blast being derived from the combustion of blast-furnace or coke-oven gas. This process, however, suffers from a number of limitations. A high-phosphorus iron is required to supply sufficient heat from its oxidation to achieve steelmaking temperatures. In addition, basic converter plants must operate on a high hot-metal charge with only a small scrap addition. The most important restricting factor, however, to the expansion of the basic Bessemer process has been the problem of quality. Consequently, steelworks making both basic Bessemer and open-hearth steels were built, the open-hearths utilizing the low-sulphur and low-phosphorus scrap arising from the basic converters, together with medium-phosphorus *stahleisen*. Continental steelworks were thus able to take advantage of the lower open-hearth operating costs resulting from a high scrap charge and also to effect a balanced economy with regard to the available raw materials.

After the war, however, the pattern of the demand for steel products and the availability of essential raw materials changed. The increasing production of consumer goods required more extensive use of deep-drawing-quality steels, and made it imperative that steels of improved quality should be available

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in greater quantities. As the existing Continental open-hearth plants could not produce the increased quantities, it became necessary to consider increasing the production from basic Bessemer converters. The expanding consumer industry also meant that existing steel plants had to be expanded and new steelworks erected, but the Continental countries, in common with most other countries, lacked capital available for investment. A third consideration, therefore, was to build steelworks with a high rate of production, but with the minimum capital outlay. The basic converter plant is known to have a comparatively low investment cost per unit of production compared with other steelmaking processes. Changes in the raw materials situation were due to the scarcity of the lower-phosphorus ores, and recourse had to be made to the more extensive use of Minette ores from the Lorraine area, permitting imported low-phosphorus ores to be used in the production of medium-phosphorus iron. Allowing that the basic converter could meet the considerations of raw materials and output, the main problem became one of quality. Later in the paper it will be shown how this problem was eliminated by the aid of oxygen in the steelmaking process.

The position in the U.K. was rather different. As on the Continent, the types of fuel used in the O.H. furnace had changed from the use of 100% producer gas to mixtures of blast-furnace and coke-oven gases, liquid fuels, or combinations of liquid fuels and coke-oven gas. At the end of World War II, when the major expansion plans were being formulated, adequate supplies of steel scrap were available and plans were in hand to supply from overseas sources good quality ore to replace the diminishing reserves of this country. Although it was realized that as the demand for steel increased the availability of scrap would tend to decrease, it was considered that there would be reasonable quantities of scrap available to meet the demands. But as this position changed it became evident that increased steel output would have to come largely from the use of higher proportions of hot metal in O.H. furnaces.

Although the basic converter process originated in the U.K., the practice suffered a gradual decline during the present century until by the middle 1920's no basic Bessemer plants existed in this country. This was largely due to the inability of the process, as it was then known, to produce steel of quality comparable with that of O.H. furnaces. During the 1930's, however, two new steelworks were put into operation utilizing the basic Bessemer process. It did not find universal favour amongst steelmakers because it was not generally acceptable as a method of producing high-quality steel. Thus when the decision was made to erect new steelworks and extend existing ones in the U.K. the reasons for basing them on existing methods of steelmaking were quite justified.

Since then, however, developments have taken place in basic Bessemer steelmaking which make it comparable with the O.H. furnace as a method of producing quality steel. The raw materials position has altered also and insufficient scrap is now available in the U.K., or from sources abroad, to ensure the O.H. furnace working with high scrap charges and its consequent effect on the final cost of the steel. It is interesting to note, therefore, that several of the largest steel-producing concerns in the U.K. have announced their intentions of achieving further increases in production by the installation of basic Bessemer converter plant. Other large steelmaking groups also intend employing the new oxygen-using techniques in their existing basic Bessemer converters. There are therefore reasonable grounds for considering that the Continental practice of a combination of basic O.H. furnaces and basic Bessemer converters using oxygen is an economic proposition in integrated steelworks in the U.K.

Although this development alone is sufficient to bring the use of oxygen for metallurgical purposes to the stage which justifies the introduction of tonnage oxygen plants in or near the steelworks, there are other developments which also use oxygen in large quantities and may influence methods of steelmaking within the next decade.

Interesting developments have taken place in the U.K. and on the Continent in the pretreatment of iron to reduce its metalloid content prior to being introduced into the O.H. furnace. Ladle pretreatment has been practised for some time in certain steelworks and developments are in hand to extend the process beyond the removal of silicon, so that metal is available for the O.H. furnace consisting virtually of carbon and iron, with a small percentage of phosphorus. Continental developments have been on the lines of the treatment of iron in special types of rotating vessel, which appear to be very successful for either pretreatment or steelmaking. It is probable, therefore, that in the future consideration will be given to the adoption of these processes in existing steelworks or to their erection in new steelworks. The melting units may then consist of a pretreatment station and either modified O.H. furnaces or large electric furnaces in which the metal is given a final refining. No doubt such plants would be capable of very high output rates, with a consequent effect on production costs.

Apart from the development of pretreatment methods, much work has been done in the U.K. using oxygen in O.H. furnaces for assisted melting by enrichment of the flame. This is likely to have a far-reaching effect on the production rates of existing furnaces, particularly those which suffer from restrictions to the air or fuel burning capacity.

OXYGEN IN THE DEVELOPMENT OF NEW AND EXISTING PROCESSES

Basic Bessemer Process

The first need for investigation into the basic Bessemer process was dictated by considerations of quality. Later, the need for higher rates of production became evident as the demand for steel increased.

One of the chief causes of low quality in basic Bessemer steel is its high nitrogen content, which seriously influences the ductility of the metal, particularly when subjected to deep-drawing operations or to conditions which bring about strain-age embrittlement. The phosphorus content also influences quality but to a much lesser degree. In the early stages of the investigations it was found that the rate of nitrogen pick-up was largely a function of temperature and contact time between air and molten iron.

To overcome the influence of temperature, methods were evolved which kept the bath temperature low during the blow and particularly towards the end of the operation. Experimental work was done on the introduction of cooling agents to the bath. Scrap, limestone, iron ore, mill scale, or combinations of all these materials were tried. Some of these additions cooled the metal by solution in the bath, whilst others relied on chemical dissociation to produce a fall in temperature. Lime is an essential raw material in the process, and so by making additions of limestone the essential constituent was provided and, at the same time, a reduction in temperature was achieved by dissociation of the carbonate. In order to reduce the contact time between air and the bath, the metal depth in the converter was reduced and the bath area extended. Although these various methods had some effect on the final nitrogen content, reducing it from 0·012–0·014% to 0·008%, the quality did not compare with O.H. steels having nitrogen contents of 0·004–0·005%. At a later date, attention was focused on the substitution by oxygen of part of the nitrogen carried in the air stream, as it was considered that by diminishing the proportion of nitrogen in the blast there would be less likelihood of it being absorbed in the metal. It was found, however, that the effect of adding oxygen was to increase the final temperature and thus increase the tendency towards nitrogen absorption. A combination of oxygen enrichment together with cooling additions of scrap, ore, or limestone, or mixtures of these three materials, was then introduced, which resulted in a further reduction in the nitrogen content of basic Bessemer steel.

Further work by Coheur and Kosmider[1] showed that the nitrogen solubility in iron during blowing in the basic Bessemer converter followed the same pattern when using oxygen-enriched air or atmospheric air. It is evident from their curves that the nitrogen content falls until about halfway through the blow, but rises again as the carbon is oxidized. A study of Sievert's law shows that as the air blast is progressively enriched with oxygen the concentration of carbon monoxide increases. Consequently the partial pressure of nitrogen in the exit gases is lowered. However, towards the end of the carbon oxidation period and during the afterblow, the concentration of carbon monoxide gradually diminishes until finally it does not exist in the exit gases. Therefore the partial pressure of nitrogen rises as it leaves the bath. Consequently its rate of absorption increases and, even with a comparatively low concentration of nitrogen in the blast, absorption occurs.

Thoughts were thus turned towards the complete elimination of nitrogen from the blast. Mixtures of nitrogen-free gases having the same thermal effect as air were considered. In Belgium and Germany experiments were conducted with two types of mixed blast. Work at the Esperance-Longdoz works in Belgium developed along the lines of using a mixture of oxygen and steam. It was found that if this was used in the proportions of about 60% oxygen and 40% steam, by weight, the same thermal conditions were produced as when blowing with air. Coheur and Kosmider showed that steel containing as little as 0·002% N_2 could be produced. As the nitrogen absorption occurred towards the end of the blow, the oxygen–steam mixture need not be introduced until after the major proportion of the carbon had been eliminated. It was also found that by using oxygen-enriched air in the early stages of the blow, high proportions of steel scrap could be added, or alternatively, additions made of limestone or iron ore. The choice between scrap and iron ore is dependent on the price of steel scrap in relation to that of molten iron. As the price of scrap rises it becomes more economical to use iron ore.

With the same object in view, other Continental workers utilized a mixture of oxygen and carbon dioxide in the proportions of 50% of each, by volume. This again has the same thermal equivalent as air. One of the principal deterrents to its adoption is the difficulty in producing a carbon dioxide virtually free from nitrogen. The method has been adopted, however, in certain Belgian steelworks.

The reduction of the phosphorus content of basic Bessemer steels has been investigated in Continental steelworks. A technique has been devised in which the afterblow is interrupted when the phosphorus is about 0·06–0·08%. A new slag containing sodium carbonate is added and a second afterblow of 15 or 20*s* is given. The final phosphorus content is reduced from the normal 0·035% to 0·015–0·025%.

The wide-scale adoption of oxygen in the basic Bessemer converter and the erection of a large number of tonnage oxygen plants clearly indicates that the method has proved both technically and economically sound under Continental conditions. The approximate cost of oxygen is between 8*s*. and 9*s*. per ton of steel made, to which must be added a small amount for the cost of steam. Although the cost of producing air at the required pressure and volume may only be one-third of this amount, the improved output and enhanced quality of the final product more than outweigh the cost differential.

Basic O.H. Process

Over the past 15 to 20 years much thought, money, and time has been expended upon laboratory research and works investigation into all aspects of open-hearth performance. These have had the supreme object of producing a greater quantity of steel per unit time at a lower cost. Flame temperature, burner design, air and fuel velocity, preheat, furnace dimension, charging facilities, refractories, aerodynamics, hot-metal proportions and composition, types and distribution of scrap in the furnace have all been studied. Many general conclusions have been drawn.

The influence of furnace size on production rates indicates that, within limits, the greater the furnace capacity the higher the rate of production, with the conclusion that, within the availability of adequate supplies of scrap and iron of a suitable composition, fixed furnaces of 200 tons capacity may offer the greatest all-round benefits and economies in hot-metal practice. The fuel consumption is also shown to fall as furnace capacity increases. The effect of hearth area on production rates has also been studied with the broad conclusion that the production rate increases as the hearth area in square feet per ton of furnace

capacity increases. Obviously there must be a limit to this relationship, which has been set at about 6 ft²/ton. The furnace checker capacity has also been the subject of discussion; the tendency has been towards large increases in the capacity of checkers. Methods of checker arrangement have received attention and double-pass checkers have been installed in a number of U.S. works. Installations have been made of types of checker fillings designed to present larger areas of heating surface to the gases passing through the regenerators. Gas flow investigations have resulted in the evolution of the single-uptake design of furnace which has been adopted by a number of U.K. steelmakers. The effect of air preheat has been the subject of several investigations in both the U.K. and the U.S.A. Cashmore[2] concluded that a 100° C increase in preheat increased the working rate of the furnaces under investigation by 0·5 tons/h. Marsh[3] concluded that an increase in air temperature of 100° F reduced the heat time by about 45 min. Flame and burner characteristics have been studied and the conclusion reached that a high fuel velocity is essential in order to obtain the maximum benefit from the fuel.

The results of these individual investigations have led to the accepted idea that one of the most important factors in achieving maximum O.H. production is to give the highest degree of preheat to the air and to endeavour to burn the maximum amount of fuel within the furnace laboratory. Having introduced the maximum fuel input into the furnace, it is axiomatic that the maximum charging rate must be maintained to absorb the heat created. If adequate charging facilities, therefore, do not exist in a melting shop, there is little purpose in increasing the thermal input in the furnace. When considering the role of oxygen for the purpose of assisted melting by flame enrichment, it must be in relation to these conditions. If, therefore, oxygen is being considered as a tool in an existing melting shop, prior study of the effect of other variables on the O.H. productivity should be made and assessed. It is of first importance that the maximum thermal input is obtained by existing means before embarking on the combustion of additional quantities of fuel with oxygen.

If, however, a new O.H. melting shop is envisaged, the influence oxygen for assisted melting would have on furnace design should be considered. Investigations have shown that when oxygen is used for flame enrichment the greatest advantage is derived in O.H. furnaces having inadequate checker capacities. Therefore it is reasonable to conclude that a furnace could be designed, having smaller than usual checkers, with oxygen enrichment used to ensure the necessary heat input into the furnace. It should be possible to construct such a furnace at a lower capital cost than the modern type of O.H. furnace, with its very large or double-pass checkers.

Theoretical Considerations of the Effect of Oxygen on Furnace Flames

Before going on to a survey of the application of oxygen for assisted melting by flame enrichment in O.H. furnaces in the U.K., some consideration of the theoretical aspects should be made.

The addition of oxygen does not, of itself, introduce any extra heat into a combustion reaction. Its virtue lies in the effect it has on combustion reactions by making more heat available than when air is used, since a disproportionate volume of nitrogen does not require to be heated. Each volume of oxygen added is equivalent to reducing the nitrogen by four volumes.

On the assumption that air is heated to 1000° C in the O.H. regenerative system and that there is a 50% efficiency of heat recovery, Thring[4] concluded that the heat lost preheating the nitrogen in the air was 7·7 therms (or 4¼ gal of oil) per ton of steel. Any reduction in the nitrogen ballast, therefore, must show a reduction in the quantity of heat lost and therefore reflect in the total fuel consumption. By burning fuel in an oxygen-enriched atmosphere a smaller quantity of nitrogen is present in the combustion products and so the flame has a higher temperature.

Heat is transferred in the O.H. furnace by conduction, convection, and radiation. Conduction of heat from the hot gases is only a small proportion of the total heat transferred since gases possess very low thermal conductivity. Much controversy has arisen regarding the quantity of heat transferred to the bath by convection and radiation. Thring[5] considered that theoretically 90% of the heat transferred to the bath in the flat melted condition was due to radiation. It would appear, however, that convective heat transfer plays a most important part during melting because the scrap and the uneven bath present large surface areas to the flame. A number of observers have pointed out that coke-oven gas flames, which are almost non-luminous and therefore have very low radiation properties, give extremely fast melting rates, which can only be accounted for by convective heat transfer.

Both forms of heat transfer are functions of flame temperature. Convective heat transfer is in direct proportion to flame temperature, whilst radiation is dependent on the fourth power of the absolute temperature. It follows, therefore, that if the flame temperature is increased by the use of oxygen enrichment, a large increase in heat transfer by radiation should follow.

Whilst it is readily agreed that oxygen used as a means of combustion produces higher temperature, Fehling[6] showed that oxygen does not of necessity produce the same effect as combustion with air. When any type of fuel is burned with air the heat content of the combustion products has a maximum value of 100 B.t.u./ft³, but if combustion takes place with pure oxygen there is a wide variation in the heat content. It may be between 300 and 500 B.t.u./ft³ depending on the type of fuel. Gaseous fuels show much lower values than liquid fuels. It would appear, therefore, that greater benefit would be derived from the combustion of the higher-grade liquid fuels with oxygen, although coke-oven gas very nearly approaches the flame temperature of fuel oil.

The standard means of obtaining high flame temperature in the O.H. furnace is by preheating the combustion air. This preheat temperature does not usually exceed 1200° C, and Fehling showed that the same combustion temperature could be achieved by enriching cold air to 39% oxygen content. The theoretical curves for flame temperature and amount

of air preheat indicate that a preheat of 1200° C will give a rise in flame temperature of 450° C, while the maximum flame temperature obtained by combustion with 100% cold oxygen is only 100° C below that obtained with a 1200° C preheat. Therefore, it is clear that preheating the oxygen-enriched air becomes relatively less effective with the higher degrees of enrichment, the greatest increases in flame temperature being obtained with enrichments up to 50%. However, although the flame temperature does not increase appreciably beyond this enrichment, the heat contents of the combustion products increase rapidly, increasing the available heat in the furnace.

The thermal efficiency of an oxygen-enriched flame is dependent on the total heat content of the combustion products at the flame temperature. Fehling calculated the total heat content of the combustion products at the maximum combustion temperature for various fuels and oxygen enrichment. He showed that up to a temperature of about 2400° C all fuels show about the same value of total heat content in the combustion products, and that the heat content was almost directly proportional to the combustion temperature. Above 2400° C, however, the fuels behaved differently and the heat contents rose out of proportion to the increases in the flame temperature, showing that the heat content of the flame is not always directly proportional to its temperature, the disparity arising from the heats of dissociation of the carbon dioxide and water vapour which rise progresively with the flame temperature.

Fehling[6] also calculated the efficiencies of furnaces at an operating temperature of 1500° C, using various percentages of oxygen in the combustion air. Table I illustrates these efficiencies, expressed as percentages.

It will be seen that the increase in efficiency is most marked in all cases with oxygen enrichment up to 40%. Whilst there is an improvement in the efficiency of the low-grade gaseous fuels as the oxygen content of the combustion air rises, it is apparent that oxygen enrichment does not give the same advantages as it does when applied to the richer fuels.

It has been stated previously that convection and radiation play the most important part in heat transfer from the flame to the metal. Natural convection plays only a very small part in comparison with forced convection, but oxygen enrichment, by increasing the flame temperature, increases the natural convective flow. Where the gas flow is not governed by temperature gradients, e.g. when forced air is used, convective heat flow is most important and contributes quite considerably to the heat transfer.

Table I

THERMAL EFFICIENCY OF THE OPEN-HEARTH FURNACE (AFTER FEHLING[6])

Fuel	Oxygen Content, %				
	21	40	60	80	100
Fuel oil	32	59	69	74	77
Coke-oven gas (cold)	32	57	66	71	74
Producer gas	12	33	40	44	46
Producer gas (Preheated)	41	43	49	52	54
Blast-furnace gas (to 500° C)	20	31	36	38	40

Whilst oxygen enrichment causes some increase in the convective heat flow by increasing the flame temperature, this method of heat transfer is more directly related to the volume flow through the furnace, with the result that, if the total volume of combustion products decreases by the use of oxygen enrichment, there will be a tendency towards a decrease in convective heat transfer. However, when considering heat transfer from oxygen-enriched flame, it should be borne in mind that large amounts of latent heat may be released by dissociation of products of combustion when high-temperature gases come into contact with relatively cool parts of the furnace and scrap.

Radiation heat transfer has been stated to be responsible, during the refining period, for about 90% of the total heat input into the bath. As the flame temperature is increased the radiation heat transfer is also increased as it is in proportion to the fourth power of the absolute flame temperature. Thus oxygen enrichment can provide an increase in heat transfer to the charge for the same fuel input.

Practical observation has shown that oil flames are shortened by oxygen enrichment of the combustion air. This is most important since it enables more fuel to be burnt in a given furnace volume, and thus a greater amount of heat is available within the furnace and more rapid melting of the charge results. Thring[7] considered that a reduction of flame length would, in nearly all cases, give an improvement in existing O.H. furnaces. For an oil flame the controlling jet fluid is the steam-atomized oil. If oxygen-enriched air is used, the flame length is decreased owing to the entrainment, by the fuel, of greater quantities of oxygen per unit volume. If high-purity oxygen is jetted into the flame the momentum of the jet has an additional shortening effect.

With gas flames the flame momentum is largely controlled by the momentum of the air and, although higher percentages of oxygen in the air tend to cause flame shortening, a decrease in total air flow would have an over-riding effect and lead to flame lengthening. To avoid the increase in flame length, oxygen should be added as a jet or jets near the gas port, so that added momentum will be introduced.

Theoretically, it has been shown very briefly that oxygen-enriched air, when used in conjunction with all types of fuel, is capable of increasing both the efficiency of combustion and the total heat transfer from the flame to the charge or to the bath. Practical limits are set to the degree of oxygen enrichment which can be employed, and to the duration. These are mainly associated with roof temperatures and end-wall and checker wear, but numerous tests over prolonged periods in the U.K. have shown that appreciable increases in production rate and economies in operating costs can be made by the use of a modest degree of oxygen enrichment. In the next paragraph, therefore, consideration is given to a discussion on the practical application in steelworks.

RESULTS OF PRACTICAL TRIALS IN STEELWORKS USING OXYGEN FOR ASSISTED MELTING BY FLAME ENRICHMENT

During the past three years the use of oxygen has become the established practice in at least three

U.K. steelworks, differing widely in character and the design and method of operation of the furnaces.

Use of Oxygen in Hot-metal Tilting Practice

The paper by Jackson, Wogin, and Johnson[8] was one of the most comprehensive published in the U.K. on the use of oxygen for assisted melting by flame enrichment. The use of oxygen for flame enrichment was investigated in hot-metal tilting furnaces using 80% hot metal in the charge. Tests were carried out on furnaces fired with pitch creosote and coke-oven gas, and also in mixed-gas-fired furnaces.

When using oxygen in conjunction with pitch creosote and cold coke-oven gas an additional 30–50 gal of pitch creosote per hour were employed. Oxygen was usually added at the rate of 20,000 ft³/h. Under normal conditions the pitch-creosote–coke-gas flame was sharp and short and combustion was completed by the end of the middle door. The use of oxygen appeared to shorten the flame by about 4 ft. As a result the charging technique was altered and scrap was piled in front of the burners in order to take advantage of the more localized melting. Three series of trials were made introducing oxygen at different periods during charging and different flow rates.

In the first series oxygen was added from the commencement of charging oxides and limestone until the roof temperature reached the permitted maximum of 1650° C. The duration of enrichment was about 3 h. Faster charging was accomplished because the furnace was capable of accepting the charge at a greater rate. The quantity of oxygen used was 200 ft³/ton, but a gain of only 2½% in output was experienced. It was concluded that this was partly because the mixture of limestone and oxides could not accept the extra heat compared with scrap. It was also practice to fettle after charging oxides and scrap, which also influenced the effect of oxygen enrichment.

In the second series, 20,000 ft³/h of oxygen were used from the commencement of scrap charging until the roof temperature reached 1650° C. The duration of enrichment was about 2 h, and 20 oxygen heats were compared with 20 control heats. During the oxygen heats an average of 36,320 ft³ of oxygen was used during an average period of 1 h 46 min. The oxygen consumption was 114·5 ft³/ton. Over a production of 80,000 tons of steel an output increase of 3·8% was obtained, equivalent to 90–100 tons of ingots per week. To gain the 3·8% increase in production during a 20-h tap-to-tap cycle, the furnace was operating 40% faster during the melting period. No wear attributable to the use of oxygen was found on the roof or blocks. The checker temperatures were normal and no damage to the uptakes was noted.

The final series on this furnace was undertaken to discover whether or not an increase in the oxygen flow rate and total oxygen consumption per ton would give rise to a further gain in the production rate. The experiment was carried out during two trial periods, the first at the end of the furnace life and the second during the early weeks of a new furnace. Oxygen heats were alternated with normal heats.

During the tests on the old furnace the oxygen heats showed an output increase of 6·2% over the non-oxygen heats when utilizing a flow rate of 25,000 ft³/h. Oxygen was used for an average time of 1 h 53 min with an average consumption of 163 ft³/ton. The production rate rose from 15·39 with non-oxygen heats to 16·35 tons/h using oxygen.

During the trials on the new furnace the oxygen flow rate fell to an average of 22,700 ft³/h owing to slight make-up of the oxygen tubes. In spite of this, however, an increase in output of 4·8% was recorded. The average oxygen duration was 1 h 55 min for a consumption of 153 ft³/ton. The production rate rose from 16·4 tons/h to 17·19 tons/h. The average for two experiments showed an increase of 5%, equivalent to an additional 120 tons of ingots per week.

An average saving of 2·5 therms/ton was made. The trial on the old furnace indicated that the 35·7 therms/ton obtained when using oxygen compared with 40·1 therms/ton when oxygen was not used. Similarly, when oxygen was used on the new furnace the heat used dropped to 32·5 from 34·9 therms/ton.

At a later date a series of trials were undertaken in which oxygen was used at a much higher rate. Again, alternate control and oxygen charges were used throughout the tests. Oxygen was added at the rate of 35,000 ft³/h, during a period of 1 h 40 min. The total quantity of oxygen was 210 ft³/ton. The output increase was 7·8%, an increase from 15·82 to 17·05 tons/h. The heat used fell to 35·1 therms/ton with oxygen from 37·9 without. For these tests oxygen was introduced through two ¾-in. pipes set to one side of the centre-line of the twin burners.

Since these trials the practice has been standardized at the rate of 25,000 ft³ of oxygen per hour during the scrap charging period.

Similar trials have been undertaken at the Frodingham Melting Shop where it has been found that, owing to the shorter charging and tap-to-tap times, it is necessary to use 35,000 ft³/h of oxygen in order to effect an increase of 5% in the output. The fuel input was increased in proportion. In this shop, with a tap-to-tap schedule of 15 h and a scrap-to-charge-metal time of 1½ h, it is necessary to decrease the latter time by 50% in order to gain 5% in output. The increase in fuel rate was made by using additional pitch-creosote.

The use of oxygen to assist combustion has also become standard practice in the mixed-gas-fired furnaces. Oxygen at 25,000 ft³/h is used during the scrap charging period and a similar gain in output is obtained. The output using oxygen has risen to 14·49 tons/h, compared with 13·89 tons/h during ordinary practice. The heat used has fallen to 41·9 therms/ton during ordinary practice compared with 43·5 therms/ton without oxygen.

Reports[9] have been received recently that some Soviet steelworks are employing oxygen for flame enrichment in the mixed-gas-fired 185-ton O.H. furnaces in which air is enriched with oxygen up to 25%. The oxygen is introduced on both sides of the gas port through two 1-in. dia. tubes inserted through water-cooled tuyeres. The oxygen used is 94% purity.

Since the introduction of oxygen in 1952 the average heat time has fallen from 9·8 to 8·0 h, equivalent to an 18·5% increase in productivity. During the same period the specific fuel consumption has fallen by 13·4%. The production increase directly attributable to oxygen is 11–16%.

Table II

OPERATING CONDITIONS DURING CHARGING AND MELTING

Oil fuel rate	300 gal/h
Thermal input	507 therms/h
Total air rate	639,000 ft³/h
Excess air rate	115,500 ft³/h
Estimated wet waste gas volume	670,800 ft³/h
Oxygen in dry exit gas	4%
Steam/oil ratio	5 : 1 lb/gal
Steam rate	1500 lb/h
Steam temperature	340° F
Oil temperature	155° F
Stack draught	1·10 w.g.

Basic roofs and forsterite checkers have been introduced and improvements made in charge preparation and handling. Taken in conjunction with the oxygen enrichment, the total gain in the rate of production was 21%. Oxygen enrichment was stated to have decreased the furnace campaign by 2·4%, mainly due to greater roof wear. This paper quotes the oxygen consumption as 35 m³/ton of 94% purity oxygen, equivalent to 1168 ft³/ton of 99·5% purity oxygen. Later information[10] indicated that during 1955 the roof life improved and tests were recorded with higher rates of oxygen flow. When the flow rate was doubled and the total quantity increased to 70 m³/ton (2336 ft³/ton), heat times as short as 3·5 h were obtained, but excessive refractory wear resulted. When utilizing combustion air enriched to 30% oxygen, regular production of four heats per 24 h was achieved. The oxygen consumption was 50 m³/ton of 94% purity oxygen, equivalent to 1650 ft³/ton of 99·5% purity oxygen. It would appear, therefore, that for this consumption of oxygen the heat time was reduced from 9·8 to 6 h with oxygen used for flame enrichment. The gain in productivity was almost 39%.

Recently trials were carried out in the U.K. in basic O.H. furnaces of 90-tons capacity. These were of the fixed type, charging 60% hot metal containing about 0·90–1·0% P. During charging and the early stages of melting, the furnaces used 300 gal/h of fuel oil and an estimated air rate of 639,000 ft³/h. The operating conditions during charging and melting are given in Table II.

Although the checker and flue capacities were sufficient for the normal firing conditions, it was considered that very little increase in the waste gas volume could be accommodated. In the initial tests, therefore, the fuel, air, and oxygen requirements were calculated to avoid increasing the combustion products. The rates used are given in Table III.

The furnace was fired with a back-atomizing type of burner. Oxygen was admitted through $\frac{3}{4}$-in. dia. pipes inserted in the water-cooled burner jackets below the oil nozzle. Air was admitted to the furnaces via

Table III

RATES USED DURING TRIALS

Oil fuel rate	366 gal/h
Thermal input	620 therms/h
Total air rate	599,000 ft³/h
Oxygen rate	32,000 ft³/h
Estimated wet waste gas volume	669,700 ft³/h

Table IV

EFFECT OF USE OF OXYGEN IN AN OIL-FIRED 90-tons CAPACITY O.H. FURNACE

	Non-oxygen Practice	Oxygen Practice: Oil Flow increased by 22% (1st series)	Oxygen Practice: Oil Flow increased by 10·6% (2nd series)
Av. tap-to-tap time	12 h	8 h 40 min	9 h 10 min
Av. fettling time	1h 45 min	1 h	1 h 10 min
Av. tons h (inc. fettling)	8·05	10·95	10·70
Av. tons h (exc. fettling)	9·35	12·90	12·53
Av. fuel rate during charging, gal/h	300	366	332
Av. oil consumption, gal/ton	27·5	20·68	22·75
Av. oxygen rate, ft³/h		31,700	20,000
Av. oxygen consumption, ft³/ton		585	786
Av. duration of enrichment		2 h	4 h 5 min

twin uptakes. Under these firing conditions the furnace was able to accept the higher fuel rate. The flame was much hotter and shorter. When the oxygen was turned off and the oil rate maintained it was evident that the furnace would be incapable of burning the additional fuel without the use of oxygen.

The average tap-to-tap time was reduced by 28%, with an increase in the production rate, expressed in tons per hour, of 36%. The fuel consumption showed a reduction of almost 25% for an oxygen consumption of 585 ft³/ton. These tests served to demonstrate the effect of additional fuel burned with oxygen in this particular furnace. It was felt, however, that the fuel and oxygen rates were excessive and were producing a very cutting flame which, when deflected by the scrap on to the furnace walls, showed a tendency towards increased wear. A further series of tests were therefore carried out, designed to use an oil flow rate of 350 gal/h, with an air rate of 600,000 ft³/h, and sufficient oxygen to burn the additional oil, allowing for an excess of 10%. Accordingly, 20,000 ft³/h of oxygen were added along with additional fuel. During the tests the average oil-fuel flow rate during charging was 332 gal/h. Under these conditions it was possible to maintain the higher fuel rate and oxygen for a much longer period than in the first series before the roof temperature rose to 1650° C. Table IV shows the average figures obtained during both series of trials.

During the second series the average tap-to-tap time was decreased by 23·6%. The productivity rate, as measured in tons per hour, increased by almost 33%, and at the same time the fuel consumption fell by 17·3% for an average oxygen consumption of 786 ft³/ton. Although the figures obtained during the second series were not as good from the point of view of output and fuel consumption, it was concluded that there would be less danger of refractory damage. Accordingly the tests were continued on this basis and over a period in which oxygen was tried on three different furnaces, an increase in production between 15% and 18% being maintained for an average oxygen consumption of 720 ft³/ton.

During the past two years the use of oxygen has become established in the O.H. shop of the Consett Iron Co., Ltd. This particular works operates O.H. furnaces using both standard O.H. practice and the duplex method. The O.H. furnaces are fired with tar and coke-oven gas, the total charge weight being about 170 tons. In the standard O.H. practice, 70% scrap and 30% hot metal are used.

Some years ago the furnace capacity was increased from about 75 tons to the present 170 tons, but owing to structural difficulties it was not possible to increase the checker and flue capacities. Speaking in October, 1955*, Mr. J. F. Allen of Consett gave some interesting details of the work which had been done in these furnaces. Prior to the introduction of oxygen, the fuel rate during charging and melting had been increased to the maximum quantity, the limit being set by the volume of waste gas which the outgoing checkers could accommodate. When the use of oxygen was considered as a means of increasing the fuel rate during charging and melting, it was necessary that the waste-gas volume should not be increased beyond the normal quantity. By decreasing the combustion air volume and adding oxygen to give 25% in the remainder, it was possible to obtain substantially greater increase in the fuel rate with no increase in the waste-gas volume.

Tests were carried out over a prolonged period and ultimately oxygen for the assisted melting of the charge by flame enrichment became standard practice. During the period of enrichment the fuel rate was increased by about 22% and maintained for 3–4 h. The increase in production rate varied according to the duration of enrichment and hence the volume of oxygen consumed per ton of steel. Using 400 ft³ of oxygen per ton of steel, an increase of 10% in the output was obtained, which increased to 33% if 800 ft³ of oxygen per ton of steel was used.

Results were recorded on four furnaces over a period of 10 months and, despite limitations in the supply of oxygen, an average gain in the working rate of 14% was obtained. With adequate supplies of oxygen from the tonnage, oxygen plant the increased working rate is expected to be not less than 25%.

At the higher rates of oxygen consumption some trouble was experienced due to localized roof and checker wear, but by the substitution of basic patches in the roof and basic bricks in the top courses of the checkers, the problem was eliminated.

Application of Oxygen for Assisted Melting by Flame Enrichment towards End of Furnace Campaign

In the preceding section it has been shown that flame enrichment has been successfully applied under a wide variety of operating and firing conditions. It is felt, therefore, that advantage could be gained in most melting shops by the use of oxygen. The essential features are that additional fuel must be used during charging and that the charging facilities must be adequate to maintain the higher charging rate. The greatest advantages are obviously gained in shops having a high proportion of cold metal in the charge or on less modern furnaces. There is every reason to believe that in modern O.H. shops with furnaces of adequate checker capacity and high hot-metal charges, increases in output can be obtained. An example of this is the Fairless Works of the United States Steel Corporation in which oxygen is used for flame enrichment in the furnaces of 275 short tons capacity. These furnaces have double-pass checkers with a total volume of 14,000 ft³, or rather more than 50 ft³/ton of steel.

Use of Oxygen for Refining in O.H. Furnace

The use of oxygen for refining O.H. melts has become established practice in the majority of works producing carbon steels below 0·10% C. Experience has shown that although the oxidation rate is higher than normal at all levels of carbon removal, the greatest advantage from the use of oxygen is in the production of low-carbon steels. Using conventional methods the rate of carbon removal falls rapidly as the carbon is removed. To maintain the reaction rate large quantities of oxide must be added to an already large slag volume. Heat must be provided to melt these additions and also to maintain the fluidity of the metal, whose melting point rises as the carbon content falls. Consequently extra heat must be provided by the flame, which is often difficult and results in a lengthy refining period with adverse effect on refractories. The effect of using oxygen in the bath as a means of speeding up the rate of carbon elimination has been shown by a number of workers. Isaac[11] showed that in a 120-ton capacity basic O.H. furnace, producing steels of 0·02–0·03% C, the time taken to reduce the C content from 0·22%, without oxygen, was 2½ h, but when an oxygen lance was introduced the time fell to 1 h. A practice was established in which lancing was commenced when the carbon was 0·23%. Additions of 15 cwt of ore and 20 cwt of lime were made to the slag. The iron content of the slag was 9·0% at this stage. Lancing continued until 5400 ft³ of oxygen had been added. A flow rate of 600 ft³/min was employed, via a 1-in. dia. pipe. A further 15 cwt of ore was then added, followed by another 4200 ft³ of oxygen. The furnace was tapped at 0·03% C with a bath temperature of 1600° C and a slag iron content of 16·0%. With standard ore practice the iron content of the slag was 30%. Less general furnace wear and bank erosion resulted, since the fuel rate was reduced during oxygen lancing and a less erosive slag was present. The gain in production rate was about 10%.

The lancing techniques suffer certain limitations. Lances require to be handled and it is often necessary to have lengths of flexible rubber hose across the furnace stage. These often interfere with the passage of traffic, particularly where ground chargers are employed. To overcome these difficulties, Kesterton[12] described a development at the Steel Company of Wales Ltd., in which oxygen is added to the bath by means of a water-cooled probe projecting into the furnace through the roof. The probe introduces oxygen to the bath 4–6 in. from the surface through a 1-in. dia. nozzle at a pressure of 210 lb/in² and a flow rate of 46,000 ft³/h. Lime and oxides are fed to the slag before jetting commences. Oxygen is usually introduced when the carbon is at 0·35%, at which

* Joint Meeting of the Institute of Mechanical Engineers and the American Society of Mechanical Engineers.

stage a sample is taken. The quantity of oxygen required to reduce the bath to 0·07% C is then estimated and no further samples are taken before tapping. Fuel is reduced to about two-thirds of the normal flow during oxygen decarburization. Commencing at 0·35% C, the rate of carbon removal is 0·14%/h under standard conditions, but when oxygen is used at a rate of 150 ft³/ton, the rate of carbon removal rises to 0·42%/h. A slight lowering of the final sulphur is experienced. The roof life is improved by 1–2 weeks. A saving of 95 min from sampling for carbon to tapping was quoted by Kesterton.

Use of Oxygen for Pretreatment of Iron before Charging to the O.H. Furnace

One of the most serious problems in O.H. steelmaking practice since the war has been the inevitable increase in the percentage of hot metal in the charge. Although the pre-war U.K. national average was rather less than 50%, the proportion of hot metal in the charge varied in different practices and ranged between 30% and 70%. Owing to the increased demand for steel and the world shortage of steel scrap, steelmakers have been obliged to use higher proportions of hot metal in O.H. furnaces. The average proportion of hot metal in O.H. furnaces in the U.K. has risen to well over 50% and in many works 80% hot-metal charges are now employed. The result has been an increase in the quantity of metalloids introduced into the furnace, with the consequent effect on refining time and a rise in operating costs.

Two of the most important elements present in iron which affect the working rate of the O.H. furnace are silicon and phosphorus. Much experimental work has been undertaken and processes are now in operation which effectively reduce both these elements, if necessary, to quite low limits. The effect of the silicon content of the hot metal on O.H. production rates was illustrated by Jackson.[13] He showed that if the silicon content in the iron was below 0·19% the production rate of a 250-tons capacity tilting furnace would be between 15·25 and 16·25 tons/h. If, however, the silicon content rose to 0·50–0·59%, the production rate fell to between 12 and 14 tons/h. One of the effects of increased metalloid content from the iron is the increase in slag bulk in the O.H. furnaces. Marshall[14] showed that an increase in the slag bulk from 11% to 21% resulted in a reduction in the working rate of a particular furnace from 6 to 5 tons/h.

Although the active mixer is capable of producing an iron of low Si content, with some reduction in phosphorus, control is largely dependent on the frequency with which metal is added and taken from the mixer. Consequently methods are desirable which give a regular quality of iron to the furnace.

The first approach towards the solution of this problem was the development of desiliconizing processes. In the U.K. the pioneer work was done at Brymbo Steelworks Ltd., where ladles containing 18 tons of metal were blown with oxygen, using a ½-in. steel lance operating at a pressure of 150 lb/in² and a flow rate of 250 ft³/min. During the blow, which occupied from 15 to 20 min, the silicon was reduced from 0·80–1·50% to 0·40–0·60%. Lime was added to form a mono-basic slag containing about 30% lime and 30% silica. It was possible to add about 5 tons of scrap to the ladle owing to the high temperature increment. When iron containing 1·50% Si was treated, the efficiency of oxygen utilization was about 85%, but was reduced to about 65% when 1% Si iron was treated.

In a recent article Davis[15] quoted a series of experiments in which the desiliconizing process was continued in order to remove phosphorus. A 30-ton capacity basic-lined ladle was used, in which was added 18 cwt of limestone, 10 cwt of mill scale, 0·5 cwt of fluorspar, and up to 25% of scrap. About 18 tons of hot metal was then poured into the ladle. Oxygen was blown until the Si content was reduced to between 0·02% and 0·10%. After the removal of silicon, part of the slag was removed and a further addition of lime and ore made. At this stage the phosphorus content was between 0·44% and 0·85%. A further blow with oxygen then followed.

After the second blow the phosphorus content of the iron was between 0·03% and 0·12%. The carbon fell from the range 3·84–4·35% to 0·53–2·5%, although the average was 1·80%. The sulphur content, which ranged between 0·032% and 0·072% before treatment, was reduced to between 0·016% and 0·060%. Manganese was substantially eliminated, falling from 1·00–1·40% to 0·08–0·36%. The oxygen consumption averaged 1355 ft³/ton. One test was carried out on iron containing 1·50% P and 0·75% Si. The final figures were 0·12% P and 0·10% Si, with a reduction in carbon from 3·90% to 1·85%. Oxygen consumption was 1733 ft³/ton of iron treated.

Desiliconizing has developed at a number of other works in the U.K. and quantities of iron up to 60 tons are being treated regularly. Experimental work has also been carried out in the U.K., which has shown that desiliconizing can be effectively carried out in the active mixer. During the course of a week, iron entering a 250-ton active mixer at 0·75–1·6% Si was reduced to 0·40%. The oxygen consumption averaged 150 ft³/ton and the efficiency of oxygen utilization based on silicon removal only was 82·5%. Oxygen was introduced through two 1-in. dia. lances at a total flow rate of 1200 ft³/min.

Very interesting experimental results have been reported by Heinrich[16] using a 'Rotor' furnace. In this method 50 tons of iron were treated in a cylindrical furnace, revolving at 2 rev/min. Tests on basic Bessemer iron showed that phosphorus was reduced from 2·09% to 0·22%. Using *stahleisen* the phosphorus was reduced from 0·50% to 0·10%. In each case the C content of the final metal was 1·15%. Compared with ladle desiliconizing, which gave 15% increase in O.H. production, it was claimed that the Rotor process increased productivity by more than 50%. No capital and operating costs of this method of pretreatment were made available but there is no reason to anticipate that these would be excessive. The oxygen consumption would probably be of the order of 2000 ft³/ton, and if the refractory consumption is not high, then this method should offer a means of producing low Si and P iron at a reasonable cost.

Both ladle and Rotor methods substantially achieve the same object. The oxygen consumptions

are similar, although the capital investment costs of the ladle treatment may be rather lower, while operating costs may be about the same. It is possible that the Rotor furnace may require a lower slag volume. If the high-P iron is pretreated to remove some silicon before entering the Rotor furnace, it should be possible to obtain a slag high in P_2O_5 which would be saleable as a fertilizer. Both methods should substantially reduce operating time in O.H. furnaces and reflect in lower operating costs.

By the adoption of processes which substantially reduce the metallurgical load, the O.H. furnace would operate only as a final refining unit. Consideration must be given, therefore, to the effect the change in practice would have on fuel requirements and the size of regenerative systems. Probably furnaces could be constructed in which regenerators could be reduced, or even eliminated. Hence considerable economies could be made in the capital investment costs.

The development of pretreatment processes also calls for consideration of their use in conjunction with large electric furnaces. Attempts at utilizing high hot-metal charges in electric furnaces have not proved altogether successful. It would appear, however, that pretreatment metal could be charged into furnaces of 150- to 200-tons capacity for final refining. Power consumption and general operating costs should be relatively low. Much smaller capacity transformers would be needed since the high electrical loads for melting would not be required. In an integrated steelworks the domestic scrap could be used partly as a coolant in the pretreatment process and the remainder in the electric furnaces.

INFLUENCE OF TONNAGE OXYGEN DEVELOPMENT ON ECONOMICS OF STEELMAKING

At present, expansion of the U.K. steel industry is imperative to meet increasing overseas and home demands. Unfortunately development programmes must be restricted owing to limitations to capital expenditure. The steel industry tends to suffer unduly under such circumstances because the ratio of invested capital to the value of the output is low by comparison with the less heavy industries. It is important, therefore, to consider steelmaking processes which have the lowest capital investment cost in relation to their output rates. Although the steel production unit in an integrated steelworks represents a comparatively small part of the total investment cost, it bears a high proportion of the production costs. Consequently, processes which have low operating costs are also most desirable.

In the concluding sections of this paper, therefore, it is hoped to show how new steelmaking techniques employing oxygen can effectively reduce operating costs. The oxygen–steam-blown Bessemer converter has proved to be a method of steelmaking capable of producing steel comparable in quality to O.H. steels, and at lower costs. Pretreatment of iron prior to the O.H. furnaces can also reduce furnace operating costs and very probably capital investment costs, since a smaller number of furnaces could produce the same output. On the other hand, an existing shop could produce at a higher rate.

Assisted melting by flame enrichment and decarburizing successfully increases production, resulting in reduced operating costs. Where new construction is being considered capital investment may be reduced by decreasing the number of furnaces.

It is not possible in a single paper to cover all alternative steelmaking schemes. New developments are taking place in what is now referred to as the Kalling or 'Kaldo' process, and the 'L–D' process, but it is proposed in this paper to show the savings in operation using oxygen in O.H. furnaces and the case for oxygen–steam-blown converters.

It will be appreciated that the economics of the use of oxygen are influenced by the size of the O.H. furnace and of the metallurgical load. It is, therefore, now proposed to consider the operating costs for alternative schemes employing O.H., with and without oxygen, and also to compare a combination of O.H. and basic Bessemer converters.

COMPARATIVE COST OF STEEL PRODUCED IN O.H. FURNACES, AND IN MIXED BASIC BESSEMER–O.H. INSTALLATIONS

In a modern steelworks the amount of iron available is usually fixed by the blast-furnace capacity available, although some control over the composition of the iron is available. Also, in modern blast-furnace practice it is usual to have furnaces capable of producing 7000 tons/week at least. This means that, for a steelworks requiring 700,000–800,000 tons of iron per annum, only two blast-furnaces will be required. On operational grounds it is usually desirable that the two furnaces should produce similar irons, but if irons of different compositions are made (e.g. by ore blending or by recycling O.H. furnace slag) then approximately equal amounts of each type should be produced.

From these assumptions three different steelmaking plants have been postulated, in which the costs of a Bessemer–O.H. system can be compared with those of an all-O.H. system. In the composite systems, it is assumed that the basic converter will employ an oxygen–steam blast. The schemes are as follows:

(1) A works which normally produces 700,000 tons of iron containing 1% P. When basic Bessemer working is required, it is assumed that the P content of the iron from one blast-furnace can be raised to 1·5% by slag recycling or by ore blending. The plant required would be:

(i) *O.H. working without oxygen*
- 2 × 600-ton active mixers
- 8 × 200-ton fixed furnaces, consuming 700,000 tons of 1% P iron per annum.

(ii) *O.H. working with oxygen*
- 2 × 800-ton inactive mixers
- 7 × 200-ton fixed furnaces, consuming 700,000 tons of 1% P iron per annum.

(iii) *Combined basic Bessemer–O.H. installation*
- 2 × 800-ton inactive mixers
- 4 × 225-ton O.H. furnaces, consuming 340,000 tons of 1% P iron per annum.
- 2 × 30-ton basic Bessemer converters, consuming 360,000 tons of 1·5% P iron per annum, using oxygen–steam blast.

(2) A works consuming 700,000 tons of iron containing 1·5% P per annum. This iron will be suitable for tilting O.H. furnaces and also for oxygen–steam basic Bessemer practice, so that a direct comparison may

Table V *a–c*

(*a*) PLANT AND BASIC MATERIAL REQUIREMENTS FOR ANNUAL STEEL OUTPUT OF 1 MILLION TONS

	O.H., no oxygen	O.H., with oxygen	O.H., combined with basic Bessemer converter
Plant, tons	Active mixers 2 × 600 Fixed O.H. furnaces 8 × 200	Inactive mixers 2 × 800 Fixed O.H. furnaces 7 × 200	Inactive mixers 2 × 800 Fixed O.H. furnaces 4 × 225 Basic Bessemer converters 3 × 30
Capital cost, £m	8·75	8·25	O.H. section: 6·0 Basic Bessemer converter section 3·5 *Total:* 9·5
Annual production, tons	1 m	1 m	O.H. 650,000 Basic Bessemer 350,000
Hot metal proportion %	68	68	O.H. 53 Basic Bessemer 92
Iron usage, tons	700,000 (1% P)	700,000 (1% P)	350,000 (1% P) 350,000 (1·5% P)
Scrap usage, tons	250,000 (internal) 70,000 (external)	250,000 (internal) 90,000 (external)	250,000 (internal) 110,000 (external)
Oxygen usage, ft³/ton	nil	Preatment 200 Flame enrichment 150 Decarburization 200	O.H. section: Pretreatment 150 Flame enrichment 450 Decarburization 150 Basic Bessemer converter 1750

(*b*) AS (*a*), WITH 700,000 TONS OF 1·5% P IRON AVAILABLE ANNUALLY

Plant, tons	Active mixers 2 × 600 Tilting furnaces 8 × 340	Inactive mixers 2 × 800 Tilting furnaces 7 × 350	Inactive mixers 2 × 800 Fixed O.H. furnaces 4 × 225 Basic Bessemer converters 3 × 30
Capital cost, £m	12·0	11·25	O.H. section 6·0 Basic Bessemer section 3·5 *Total:* 9·5
Annual production, tons	1 m	1 m	O.H. 650,000 Basic Bessemer 350,000
Iron usage (1·5% P), tons	700,000	700,000	O.H. 340,000 Basic Bessemer 360,000
Scrap usage, tons	326,000	339,000	370,000
Oxygen usage, ft³/ton	nil	Pretreatment 200 Flame enrichment 200 Decarburization 150	O.H. section: Pretreatment 150 Flame enrichment 450 Decarburization 150 Basic Bessemer section 1750

(*c*) AS (*a*), WITH 750,000 TONS OF 1·5% P IRON AVAILABLE ANNUALLY

	Tilting O.H. furnaces, no oxygen	Tilting O.H. furnaces, with oxygen	O.H. and Basic Bessemer combined	
			Scheme (*a*)	Scheme (*b*)
Plant, tons	Active mixers 2 × 600 Tilting furnaces 8 × 350	Inactive mixers 2 × 800 Tilting furnaces 7 × 350	Inactive mixers 2 × 800 Fixed O.H. 5 × 200 Basic Bessemer converters 3 × 30	Inactive mixers 2 × 800 Fixed O.H. 4 × 225 Basic Bessemer converters 3 × 35
Capital cost, £m	9·5	8·25	O.H. section 6·5 Basic Bessemer section 3·5	O.H. section 6·0 Basic Bessemer section 3·75
Annual production, tons	1 m	1 m	O.H. 650,000 Basic Bessemer 350,000	O.H. 600,000 Basic Bessemer 400,000
Iron usage (1·5% P), tons	750,000	750,000	O.H. 390,000 Basic Bessemer 360,000	O.H. 340,000 Basic Bessemer 410,000
Scrap usage, tons	277,000	289,000	320,000	320,000
Oxygen usage, ft³/ton	nil	Pre-treatment: 200 Flame enrichment 150 Decarburization 200	O.H. section: Pretreatment 150 Flame enrichment 450 Decarburization 150 Basic Bessemer section 1750	O.H. section: Pretreatment 150 Flame enrichment 450 Decarburization 150 Basic Bessemer section 1750

Table V*d*

PLANT AND BASIC MATERIAL REQUIREMENTS FOR ANNUAL STEEL OUTPUT OF 1 MILLION TONS WITH 850,000 TONS OF 1·5% P IRON AVAILABLE.

	Basic electric and basic Bessemer combined	
Plant, tons	Inactive mixers	2 × 1000
	Electric furnaces	2 × 70
	Basic Bessemer converters	5 × 35
Capital cost, £m	Basic Bessemer plant	6·5
	Electric furnaces	1·8
Annual production, tons	Electric furnaces	175,000
	Basic Bessemer	825,000
Iron usage (1·5% P), tons		850,000
Scrap usage, tons		250,000
Oxygen usage, ft³/ton	Electric furnaces	400
	Basic Bessemer converters	1750

be made without any assumptions regarding differential iron costs. The plant requirements would then be:

(i) *O.H. working without oxygen*
2 × 600-ton active mixers
8 × 350-ton tilting furnaces, consuming 700,000 tons of 1·5% P iron per annum.

(ii) *O.H. working with oxygen*
2 × 800-ton inactive mixers
7 × 350-ton tilting furnaces, consuming 700,000 tons of 1·5% P iron per annum.

(iii) *Combined basic Bessemer–O.H. installation*
2 × 800-ton inactive mixers
4 × 225-ton fixed O.H. furnaces, consuming 340,000 tons of 1·5% P iron per annum.
3 × 30-ton basic Bessemer converters, consuming 360,000 tons of 1·5% P iron per annum.

(3) To include the case of a works requiring to consume as little as possible of external scrap, a works consuming 750,000 tons per annum of 1·5% P iron has been considered.

In this case, two different basic Bessemer–O.H. systems have been considered: scheme (*a*) in which the O.H. furnaces produce 650,000 tons and the converters 350,000 tons per annum (as in the preceding case), and scheme (*b*) in which the proportions are 600,000 tons from O.H. and 400,000 tons from the converters. Higher proportions of basic Bessemer steel were not considered, as it was thought that it would lead to an O.H. shop too small for efficient working. The plant requirements of the various schemes are:

(i) *O.H. working without oxygen*
2 × 600-ton active mixers
8 × 350-ton tilting furnaces, consuming 750,000 tons of 1·5% P iron per annum.

(ii) *O.H. working with oxygen*
2 × 800-ton inactive mixers
7 × 350-ton tilting furnaces, consuming 750,000 tons of 1·5% P iron per annum.

(iii) *Combined basic Bessemer–O.H. installation*
Scheme (*a*): 2 × 800-ton inactive mixers
5 × 200-ton fixed furnaces, using 390,000 tons of 1·5% P iron per annum
3 × 30-ton basic Bessemer converters, using 360,000 tons of 1·5% P iron per annum

(iv) *Combined basic Bessemer–O.H. installation*
Scheme (*b*): 2 × 800 ton inactive mixers
4 × 225-ton fixed furnaces, using 340,000 tons of 1·5% P iron per annum
3 × 35-ton basic Bessemer converters, using 410,000 tons of 1·5% P iron per annum.

Details of these installations are given in Tables V *a–c*. In these tables, the capital costs have been established from published data.

Table VI*a* and *b*

(*a*) RAW MATERIALS REQUIRED PER TON OF STEEL PRODUCED

Material	Price	O.H., no oxygen	O.H., with oxygen	Composite Plant	
				O.H.	Basic Bessemer
		tons			
Liquid iron, 1·0% P	£13·5/ton	0·70	0·70	0·55	...
Liquid iron, 1·5% P	£13/ton	...	...	...	1·03
Scrap	£12/ton	0·32	0·34	0·49	0·08
Ore/scale	£6·05/ton	0·16	0·13	0·10	...
Limestone	£1·225/ton	0·15	0·15	0·12	...
Lime	£4·2/ton	...	...	...	0·14
Dolomite	£5·5/ton	0·036	0·036	0·036	0·015
Ferro-silicon (45%)	£47/ton	0·002	0·002	0·002	0·002
Ferro-manganese (78%)	£68/ton	0·007	0·007	0·007	0·007
Oxygen	5*s.*/1000 ft³	...	550 ft³	750 ft³	1750 ft³
Fuel oil (Medium S)	10*d.*/gal	22 gal	20 gal	20 gal	...
Steam	10*s.*/1000 lb	...	...	...	100 lb
Ingots produced		1·00	1·00	1·00	1·00
Scrap (for credit)	£12/ton	0·01	0·01	0·01	0·01
Slag (for credit)	£1·5/ton	...	...	...	0·20

(*b*) AS (*a*), WITH 700,000 TONS OF 1·5% P IRON AVAILABLE ANNUALLY

Liquid iron (from B.F.)	£13/ton	0·700	0·700	0·523	1·03
Active mixer metal	£13·625/ton	0·735	...	...	...
Desiliconized metal	£13·25/ton	...	0·700	0·523	...
Scrap	£12/ton	0·291	0·339	0·527	0·08
Ore/scale	£6·05/ton	0·14	0·12	0·11	...
Limestone	£1·225/ton	0·13	0·13	0·13	...
Lime	£4·2/ton	...	...	...	0·14
Dolomite	£5·5/ton	0·028	0·028	0·036	0·015
Ferro-silicon (45%)	£47/ton	0·002	0·002	0·002	0·002
Ferro-manganese (78%)	£68/ton	0·007	0·007	0·007	0·007
Oxygen	5*s.*/1000 ft³	...	550 ft³	750 ft³	1750 ft³
Steam	10*s.*/1000 lb	...	...	...	100 lb
Fuel oil (Medium S)	10*d.*/gal	22 gal	20 gal	20 gal	...
Ingots produced		1·00	1·00	1·00	1·00
Scrap (for credit)	£12/ton	0·01	0·01	0·01	0·01
Slag (for credit)	£1·5/ton	0·15	0·15	...	0·20

The raw materials requirements of the various schemes are given in Tables VI *a–c*. These are based on published information, but for simplicity it has been assumed that the O.H. processes employ limestone alone rather than limestone–lime mixtures, and that the 'finishings' are constant for all the methods used. It is assumed that materials requirements for oxygen–steam basic Bessemer working are similar to those for air-blowing.

The actual costs have been worked out in Tables VII *a–c*. The materials costs are based on current market prices of steelmaking materials, except that 'accounting' costs have been used for iron and scrap. For iron, it is assumed that the accounting cost is £13 10*s.*/ton for 1·0% P grade, and £13/ton for the 1·5% P grade. For scrap, a uniform price of £12/ton has been assumed.

Common amounts have been assumed for pouring costs, general repairs, and maintenance (i.e. other than the furnaces or converters), departmental charges (supervision, consumable stores, loose tools, etc.), general services (laboratories, railways, etc.), and administration and management. These are considered reasonably representative of present practice.

Table VII*a* shows that it is cheaper to run a mixed basic Bessemer–O.H. installation rather than an all-O.H. works. Tables VII *b* and *c*, however, show that tilting O.H. furnaces, used with oxygen for flame enrichment, decarburization, and pretreatment, may be slightly cheaper to operate than a combined basic

Table VIc

(c) AS (a), WITH 750,000 TONS OF 1·5% P IRON AVAILABLE ANNUALLY

Material	Price	O.H. no Oxygen	O.H. with Oxygen	Composite Scheme (a)		Composite Scheme (b)	
				O.H.	Basic Bessemer	O.H.	Basic Bessemer
Liquid iron (from B.F.)	£13·0/ton	0·75 ton	0·75 ton	0·567 ton	1·03 ton	0·600 ton	1·03 ton
Active mixer metal	£13·625/ton	0·788 ton	...	...	...	...	...
Desiliconized metal	£13·25/ton	...	0·75 ton	0·567 ton	...	0·600 ton	...
Scrap	£12·0/ ton	0·277 ton	0·289 ton	0·483 ton	0·08 ton	0·450 ton	0·08 ton
Ore/scale	£6·05/ton	0·15 ton	0·13 ton	0·11 ton	...	0·11 ton	...
Limestone	£1·15/ton	0·14 ton	0·14 ton	0·13 ton	...	0·13 ton	...
Lime	£4·0/ton	...	...	...	0·14 ton	...	0·14 ton
Dolomite	£47·0/ton	0·028 ton	0·028 ton	0·036 ton	0·015 ton	0·036 ton	0·015 ton
Ferro-silicon, 45%	£5·5 ton	0·02 ton	0·002 ton	0·002 ton	0·002 ton	0·002 ton	0·002 ton
Ferro-manganese, 78%	£68·0/ton	0·007 ton	0·007 ton	0·007 ton	0·007 ton	0·007 ton	0·007 ton
Oxygen	5s./1000 ft³	...	550 ft³	...	1750 ft³	...	1750 ft³
Steam	10s./1000 lb	...	...	...	100 lb	...	100 lb
Fuel oil (Medium S)	10d/gal	22 gal	20 gal	20 gal	...	20 gal	...
Ingots produced		1·00 ton	1·00 ton	1·00 ton	1·00 ton	1·00 ton	1·00 ton
Scrap (for credit)	£12·0/ton	0·01 ton	0·01 ton	0·01 ton	0·01 ton	0·01 ton	0·01 ton
Slag (for credit)	£1·5/ton	0·18 ton	0·18 ton	...	0·20 ton	...	0·20 ton

Table VId

(d) AS (a) WITH 850,000 TONS OF 1·5% P IRON AVAILABLE ANNUALLY

Items	Price	Electric Furnace	Basic Bessemer
	£ s. d.		
Liquid iron	13 0 0/ton		1.03 tons
Scrap	12 0 0/ton	1·03 tons	0·08 tons
Limestone	1 4 6/ton	0·020 tons	
Lime	4 4 0/ton	0·030 tons	0·14 tons
Dolomite	5 10 0/ton	0·030 tons	0·015 tons
Ferro-silicon (45%)	47 0 0/ton	0·002 tons	0·002 tons
Ferro-manganese (78%)	68 0 0/ton	0·007 tons	0·007 tons
Oxygen	5 0/1000 ft³	400 ft³	1750 ft³
Steam	10 0/1000 lb		100 lb
Power	1/unit	550 kWh/ton	
Electrodes	1 10 lb	12 lb/ton	
Ingots produced		1·00 ton	1·00 ton
Scrap (for credit)	12 0 0/ton	0·01 ton	0·01 ton
Slag (for credit)	1 10 0/ton		0·20 ton

Bessemer–O.H. installation. Such furnaces work efficiently with an iron containing 1·5% P, and the extension of the use of oxygen during the major portion of the refining period could give further improvements in efficiency and costs. Water-cooled roof or back-wall probes could provide suitable means of injecting oxygen during this period.

COMPARATIVE COST OF STEEL PRODUCED IN BASIC BESSEMER–ELECTRIC INSTALLATIONS (TABLES Vd, VId, AND VIId)

The previous section indicates that as the proportion of basic Bessemer steel increases in basic Bessemer–O.H. composite plants, the total steelmaking cost decreases. It seems logical, therefore, to endeavour to produce the maximum quantity by this process and less by the O.H. process. However, the operation of perhaps three O.H. furnaces as part of a composite plant might not prove very economical. On the other hand, a maximum proportion of basic Bessemer steel could be produced in a plant using electric furnaces as the auxiliary melting medium, in which a charge of 100% steel scrap would be melted and all the iron used for conversion in the Bessemer plant.

Assuming the availability of 850,000 tons of 1·5% P iron and 250,000 tons of scrap arising within the works, the composite plant could produce 1 million ingot tons per year in the proportion of 82·5 basic Bessemer steel to 17·5 electric steel. The production costs have been estimated in Table VII*d*, which indicates a composite cost lower than the combined Bessemer–O.H. shops based, of necessity, on a higher percentage of O.H. production.

TONNAGE OXYGEN PLANTS

Review of Developments

In the previous sections of this paper attention has been given to the use and application of tonnage oxygen in steel production, and since the indications are that oxygen will play an increasingly important part in steelmaking, it will be of interest to review the developments which have taken place in the design and construction of tonnage plants (Figs. 1–7).

The present designs used in tonnage plants have been developed from the early classical cycles used for the production of gaseous oxygen. The earliest low-temperature processes for air separation resulted in only a portion of the oxygen becoming available for use and, although all the air became liquefied during the process, the fact that the product gases left the equipment at normal temperature meant that refrigeration was only necessary to reduce the plant temperature initially and to overcome cold loss. Thus the efficiency of refrigeration was then of second-order importance and, indeed, the original Linde cycle depended exclusively on the Joule–Thomson effect which is of low thermodynamic efficiency.

The demand for purer oxygen and the advantages which were apparent in the production and handling of liquid oxygen brought about the development of the double column (Linde) and the use of an expansion engine (Claude), and whilst these devices more or less stabilized the procedure for the production of liquid oxygen, steady technical progress developed the process to a higher state of thermodynamic efficiency.

Liquid oxygen is particularly convenient to use when demand is intermittent or when the highest purities are essential, but because of the extra refrigeration required it is expensive to produce. In the metallurgical field, where oxygen is required in very large quantities, cost becomes a limiting factor for fullest application of the inherent advantages and

for such purposes the gaseous oxygen production process had to be improved in efficiency.

When producing liquid oxygen the degree of refrigeration necessary involves the use of high initial operation pressures and in consequence gas-flow frictional losses are low and compact reciprocating expansion engines are feasible, leading to relatively good thermodynamic efficiency for the process as a whole.

On attempting to improve gaseous oxygen production efficiencies, and thus lower the cost, difficulty is immediately encountered because any reduction of working pressure increases the volume of gas flowing and leads to the need for bigger heat exchangers with higher proportional friction loss. Further, the reciprocating expansion engine becomes larger and less efficient and prepurification of the air involves larger and more energy-consuming equipment because of the difficulties of treating adequately such large volumes of air. Thus it was evident that the mechanical side of gaseous oxygen production plant had to undergo change if large quantities were to be manufactured cheaply. In addition, the degree of thermodynamic irreversibility of the classical gaseous oxygen cycle leads also to inefficiency, and the successful development of a low-pressure process required improvements in this respect.

The three chief factors which have successfully reduced the cost of large-scale or tonnage oxygen production are:

(i) The adaptation by Frankl of the principle of the thermal regenerator to low-temperature practice, which at the same time provided not only an efficient means of cooling a gas at low pressure but also a simple procedure for removal of carbon dioxide and water vapour from the air stream, thus eliminating the need for prepurification by chemical means

(ii) The development of the expansion turbine, which is a most suitable device for the expansion of large quantities of gas through a small pressure difference

(iii) The fundamental improvement in thermodynamic efficiency of operation of the rectification column by modification in method of operation.

The first development of tonnage plants can be attributed to Linde–Frankl equipment utilizing regenerators and the double column.

The classical Linde double column, however, had relatively fixed operating conditions which resulted in an excess of reflux, particularly in the upper column, and an early approach to improving this condition

Table VII*a* and *b*

(*a*) STEELMAKING COSTS (PER TON OF INGOTS) USING DIFFERENT STEELMAKING METHODS

Item	O.H., no oxygen	O.H., with oxygen	Composite Plant	
			O.H.	Basic Bessemer
Materials	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Liquid iron	9 9 0	9 9 0	7 8 6	13 7 10
Scrap	3 16 9	4 1 7	6 2 5	19 2
Ore and scale	19 4	15 9	12 1	...
Limestone	3 8	3 8	2 11	...
Lime	...	...	...	11 9
Dolomite	3 11	3 11	3 11	1 8
Ferro-silicon, 45%	1 10	1 10	1 10	1 10
Ferro-manganese, 68%	9 6	9 6	9 6	9 6
Fuel oil	18 4	16 8	16 8	...
Oxygen	...	2 9	3 9	8 9
Steam	...	...	...	1 0
Total materials	16 0 4	16 4 8	16 1 7	16 1 6
Standing charges	14 0	13 2	14 9	16 0
Direct operating costs				
Productive wages	5 9	5 0	5 0	4 0
Raw-materials stock-yard	3 6	3 6	4 9	1 6
Pouring costs	5 0	5 0	5 0	5 0
Mixer or pretreatment costs	8 9	3 6	3 0	...
Repairs and maintenance				
Furnaces or converters	10 0	9 0	9 0	6 0
General	6 0	6 0	6 0	6 0
Departmental charges	3 9	3 9	3 9	3 9
General services	5 0	5 0	5 0	5 0
Administration and Management	1 3	1 3	1 3	1 3
Gross cost	19 3 4	18 19 10	18 19 1	18 10 0
Less: Scrap credit	2 5	2 5	2 5	2 5
Slag credit	...	...	...	6 0
Net production cost	19 1 9	18 17 5	18 16 8	18 2 10
Composite			£18 11 4	

(*b*) AS (*a*,) WITH 700,000 TONS OF 1·5% P IRON AVAILABLE ANNUALLY

Item	O.H., no oxygen	O.H., with oxygen	Composite Scheme	
			O.H.	Basic Bessemer
Materials	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Liquid iron	10 0 2	9 5 6	6 18 7	13 7 10
Scrap	3 9 10	4 1 4	6 6 6	19 2
Ore and scale	16 11	13 3	13 3	...
Limestone	3 2	3 2	3 2	...
Lime	...	...	...	11 9
Dolomite	3 1	3 1	3 11	1 8
Ferro-silicon, 45%	1 10	1 10	1 10	1 10
Ferro-manganese, 68%	9 6	9 6	9 6	9 6
Fuel oil	18 4	16 8	16 8	...
Oxygen	...	2 9	3 9	8 9
Steam	...	...	...	1 0
Total materials	16 2 10	15 17 1	15 17 4	16 1 6
Standing charges	19 0	18 0	14 9	16 0
Direct operating costs				
Productive wages	5 0	4 2	5 0	4 0
Raw-materials stock-yard	3 6	3 6	5 0	1 6
Pouring costs	5 0	5 0	5 0	5 0
Mixer or pretreatment costs	(Included in iron price)			
Repairs and maintenance				6 0
Furnaces or converters	7 6	7 6	9 0	6 0
General	6 0	6 0	6 0	3 9
Departmental charges	3 9	3 9	3 9	5 0
General services	5 0	5 0	5 0	1 3
Administration and management	1 3	1 3	1 3	
Gross cost	18 18 10	18 11 3	18 12 1	18 10 0
Less: Scrap credit	2 5	2 5	2 5	2 5
Slag credit	4 6	4 6	...	6 0
Net production cost	18 11 11	18 4 4	18 9 8	18 1 7
Composite cost			£18 6 11	

Table VIIc

(*c*) AS TABLE VII*a* WITH 750,000 TONS OF 1·5% P IRON AVAILABLE ANNUALLY

	O.H., no oxygen	O.H., with oxygen	Composite Scheme (*a*)		Composite Scheme (*b*)	
			O.H.	Basic Bessemer	O.H.	Basic Bessemer
Materials	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Liquid iron	10 14 9	9 18 9	7 10 3	13 7 10	7 19 0	13 7 10
Scrap	2 17 4	3 9 4	5 15 11	19 2	5 8 0	19 2
Ore/scale	18 2	14 4	13 4	...	13 4	...
Limestone	3 5	3 5	3 2	...	3 2	...
Lime	...	...	...	11 9	...	11 9
Dolomite	3 1	3 1	3 11	1 8	3 11	1 8
Ferro-silicon (45%)	1 10	1 10	1 10	1 10	1 10	1 10
Ferro-manganese (78%)	9 6	9 6	9 6	9 6	9 6	9 6
Fuel oil	18 4	16 8	16 8	...	16 8	...
Oxygen	...	2 9	3 9	8 9	3 9	8 9
Steam	...	...	...	1 0	...	1 0
Total materials	16 6 5	15 19 8	15 18 4	16 1 6	15 19 2	16 1 6
Standing charges	19 2	18 0	14 10	16 0	14 9	15 0
Direct operating costs						
Productive wages	5 0	4 2	4 9	4 0	5 0	3 9
Raw materials stockyard	3 0	3 0	4 6	1 6	4 0	1 6
Pouring costs	5 0	5 0	5 0	5 0	5 0	5 0
Mixer or pre-treatment costs	(Included in Iron Price)					
Repairs and maintenance						
Furnaces or converters	7 6	7 0	9 0	6 0	9 0	6 0
General	6 0	6 0	6 0	6 0	6 0	6 0
Departmental charges	3 9	3 9	3 9	3 9	3 9	3 9
General services	5 0	5 0	5 0	5 0	5 0	5 0
Administration/management	1 3	1 3	1 3	1 3	1 3	1 3
Gross cost	19 1 11	18 12 10	18 12 5	18 10 0	18 12 11	18 8 9
Less: Scrap credit	2 5	2 5	2 5	2 5	2 5	2 5
Slag credit	5 5	5 5	...	6 0	...	6 0
Net production cost	18 14 1	18 5 0	18 10 0	18 1 7	18 10 6	18 0 4
Composite cost	...	...	£18 7 1		£18 6 5	

utilized the principle, due to Lachmann, of blowing air direct into the upper column, thus reducing the reflux ratio. A later development involved the expansion of a proportion of the nitrogen from the lower column through a turbine which has the same effect of reducing reflux to the upper column and simultaneously producing cold.

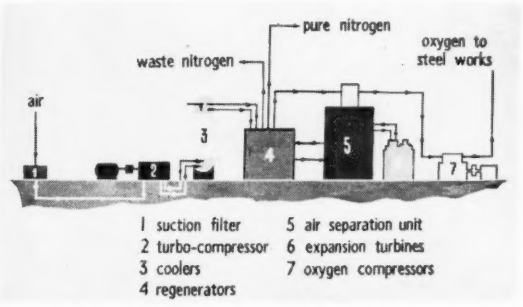

Fig. 1—Flow diagram of manufacturing process of tonnage oxygen for Steel Co. of Wales Ltd., Margam

Further developments of the double column, involving variants of methods for improving thermodynamic efficiency, are contained in the Oxyton Process and the Kellogg circuit developed in the U.S.A. in which a separate stream of air is expanded into the upper column through a turbine.

There have been several subsequent developments of the double-column design but one of the most efficient rectification cycles yet developed involves the use of a single column in the Rescol cycle.

In the U.K. considerable developments are taking place in the use of tonnage oxygen for steelmaking. At present the total planned capacity exceeds 1000 tons of oxygen per day. Of this total 900 tons/day will be based on plants operating on the Rescol cycle. The first two 100 tons/day plants are in operation

Table VII*d*

(*d*) AS (*a*) WITH 850,000 TONS OF 1·5% P IRON AVAILABLE ANNUALLY

Item	Composite Scheme (*c*)	
	Basic Electric	Basic Bessemer
	£ s. d.	£ s. d.
Materials		
Liquid iron		13 7 10
Scrap	12 4 0	19 2
Limestone	6	
Lime	2 7	11 9
Dolomite	3 4	1 8
Ferro-silicon (45%)	1 10	1 10
Ferro-manganese (78%)	9 6	9 6
Power	2 5 10	
Electrodes	1 2 0	
Oxygen	2 0	8 9
Steam		1 0
Total materials	16 11 7	16 1 6
Standing charges	16 5	12 7
Direct operating costs		
Productive wages	6 0	3 3
Raw materials stockyard	1 6	1 6
Pouring costs	5 0	5 0
Repairs and maintenance		
Furnaces or converters	10 0	6 0
General	4 0	6 0
Departmental charges	3 9	3 9
General services	5 0	5 0
Administration and management	1 3	1 3
Gross Cost	19 4 6	18 5 6
Less: Scrap credit	2 5	2 5
Slag credit		6 0
Net production cost	19 2 1	17 17 5
Composite cost	£18 1 9	

supplying tonnage oxygen to the Steel Company of Wales at Margam, and to the Consett Iron Company's works at Consett. In certain instances central plants are being installed in the U.K. to supply a number of works, since the cost of production falls with the scale of output and hence many advantages arise from centralized production. The Rescol cycle can be employed in single units up to 400 tons/day capacity with oxygen purities of 99·5%. If necessary, high-purity nitrogen can also be produced for annealing.

One of the problems linked with the supply of tonnage oxygen to steelworks, when used in O.H. furnaces and/or converters, together with the main supply of oxygen for scrap cutting, hot deseaming etc., is the variations in the hourly and daily rate of supply. One of the features of the Rescol cycle is the flexibility ratio which allows the gas-make to be reduced and the surplus output stored as liquid.

A typical flow-sheet for a 100 tons/day Rescol unit is shown in Fig. 8 and can be described, briefly, as follows: air is drawn into the plant by the turbo-compressor which provides two streams of air at low pressure and intermediate pressure. Both air-streams are cooled in two stages by direct and indirect cooling and then passed to the regenerators. The intermediate-pressure air is split after the direct cooler, passed through CO_2 absorbers, and boosted to a pressure of 3500 lb/in^2; this air is then dried and expanded. The low-pressure air is cooled to 180° C in one or other of the alternate regenerators. During the cooling process the water vapour and the CO_2 are condensed and collected in the regenerators. When one pair of regenerators is on air, nitrogen is passed through the other in the reverse direction. The packing is recooled and the water vapour and CO_2 removed. Changeover of regenerators takes place automatically at fixed periods. Balancing of the regenerators required to permit complete re-evaporation of the carbon dioxide deposits is effected by means of the high-pressure balancing circuit. The high-pressure air is purified separately without passing through the regenerators and the necessary excess of separation products thereby assured. On leaving the regenerators the low-pressure air is scrubbed and cooled to dew point with liquid air in the low-pressure equalizer. In this way any residual impurities are removed. Rich liquid from the equalizer is freed from the solid impurities in one of the filters and expanded into the column. Low-pressure air vapour leaving the equalizer is heated by exchanging with expanded high-pressure air condensing into the column by means of the turbine. Preheating is necessary to prevent liquefaction in the turbine. The low-pressure air is purified and cooled to approximately — 175° C in the regenerators and passed to the low-pressure equalizers in which it is scrubbed with liquid air from the high-pressure circuit. The vapour from the equalizer slightly enriched in nitrogen is liquefied by heat exchange with boiling oxygen in the condenser/reboiler, sub-cooled by waste nitrogen in the exchanger, and expanded as reflux into the top of the column. Liquid

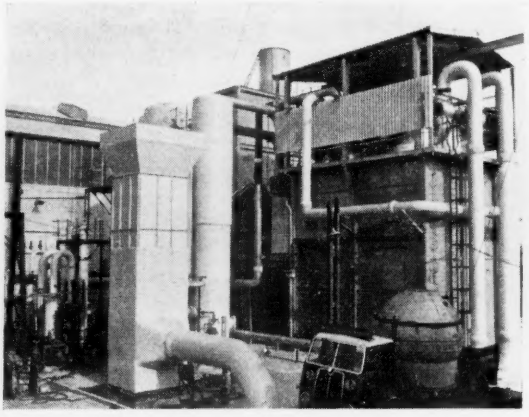

Fig. 2—Regenerator unit with column in background for 100 tons/day plant at Margam

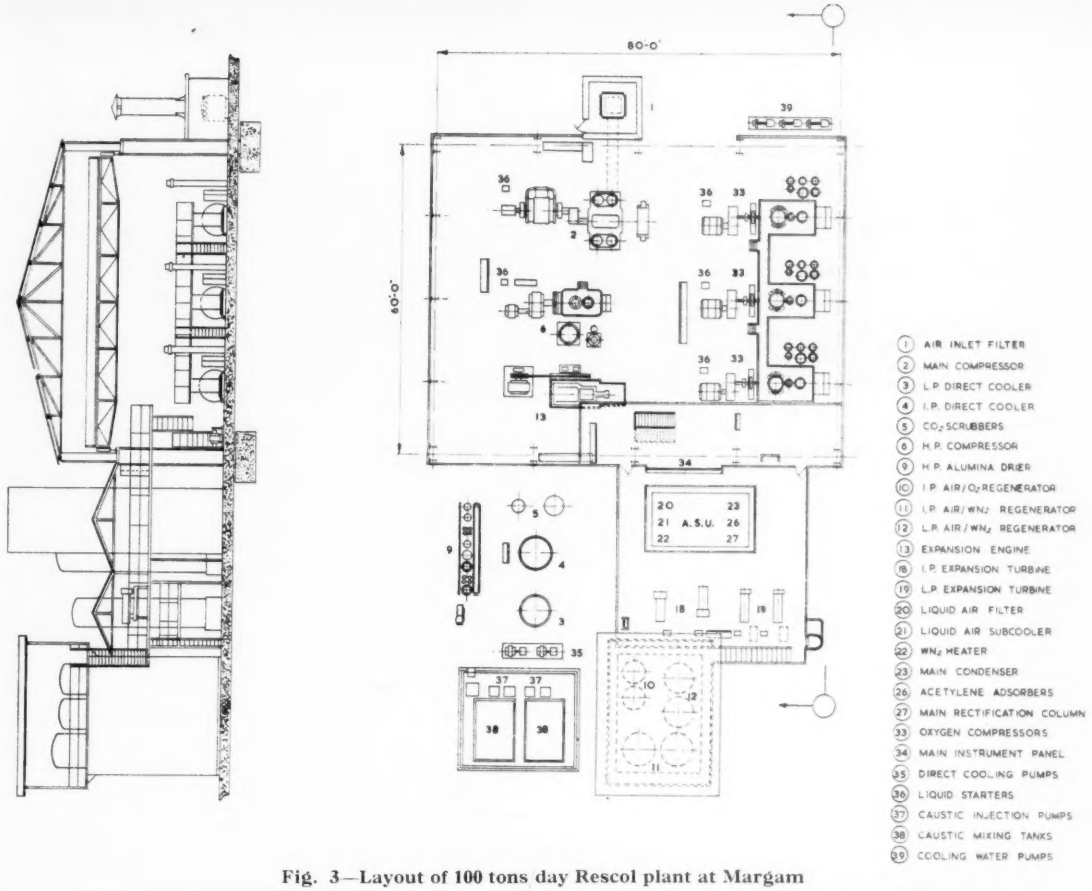

Fig. 3—Layout of 100 tons day Rescol plant at Margam

oxygen from the column sump is circulated through the condenser by pumps. Rich liquid from the intermediate-pressure equalizer is expanded into the low-pressure equalizer, and used for scrubbing the low-pressure air. The relatively cold expanded high-pressure air from the expansion engine is further cooled and partly liquefied in the exchanger. The air is then completely condensed in a condensing coil in the column sump, expanded into the inter-

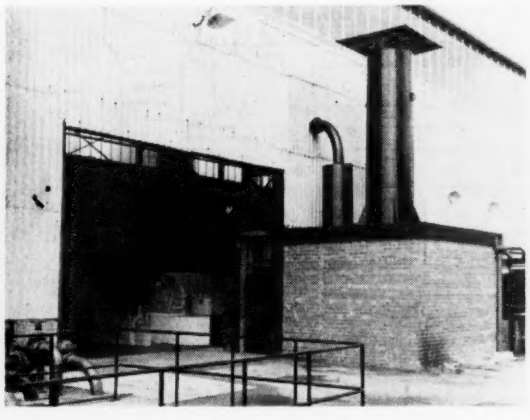

Fig. 4—Air intake and silencer for 100 tons day plant at Margam

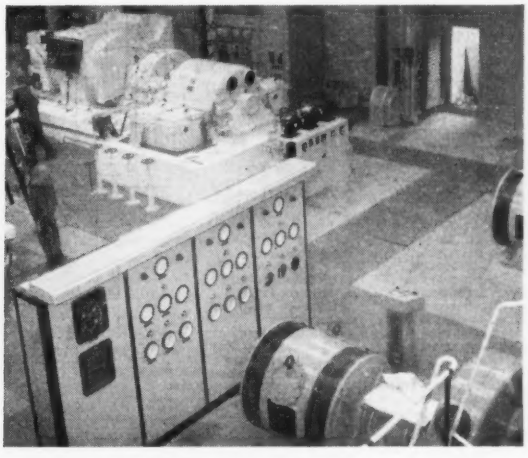

Fig. 5—Main air compressor with oxygen compressor control panel in foreground for 100 tons day plant

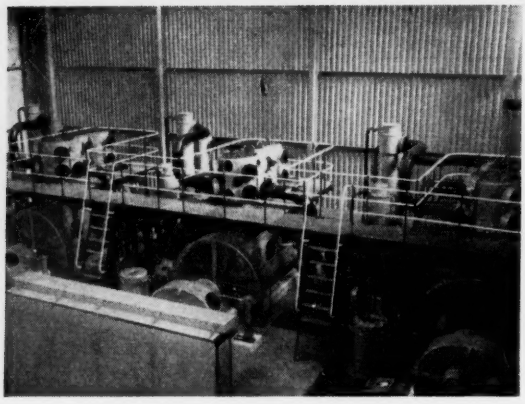

Fig. 6—Tonnage oxygen compressors for 100 tons/day plant

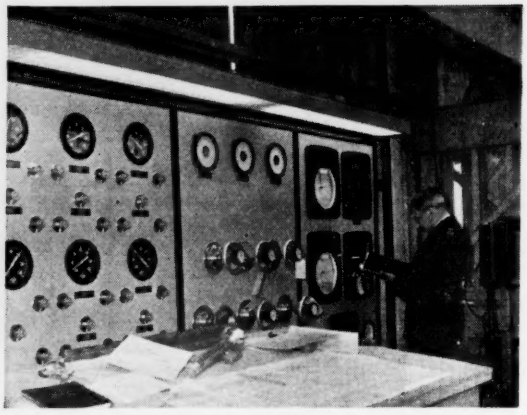

Fig. 7—Section of main control panel for 100 tons/day plant

mediate pressure equalizer and used to scrub the intermediate-pressure air. Waste nitrogen from the column is heated in the liquid-air subcooler after which it is split into two streams. One stream after temperature adjustment is passed directly to the low-pressure air regenerators, warmed to approximately atmospheric temperature; the other is further heated in the waste nitrogen heater and passed to the intermediate-pressure air regenerator. On leaving the regenerators the nitrogen is discharged to atmosphere through the vaporization cooler in which it is used to recool the water for the air direct coolers. The gaseous oxygen product from the column is warmed in the intermediate-pressure air–oxygen regenerators and in the high-pressure air–oxygen heater before being passed to the gas storage and handling section. Liquid oxygen is removed from the column by means of the circulating pumps. Part of this oxygen is circulated through the main condenser and back to the column, part is circulated through the acetylene absorbers and back to the column, while the remainder is pumped to the liquid-oxygen storage by means of the transfer pumps. For operation at reduced gaseous oxygen demand, intermediate-pressure air turbines are provided. A portion of the intermediate-pressure air is not condensed but is directed to the intermediate-pressure air turbine preheater in which it is heated by condensing expanded high-pressure air. The intermediate-pressure air is then expanded through the turbine into the column. In this way additional liquid oxygen, which can be stored conveniently, is obtained by reducing the total yield. The cold production of the intermediate-pressure

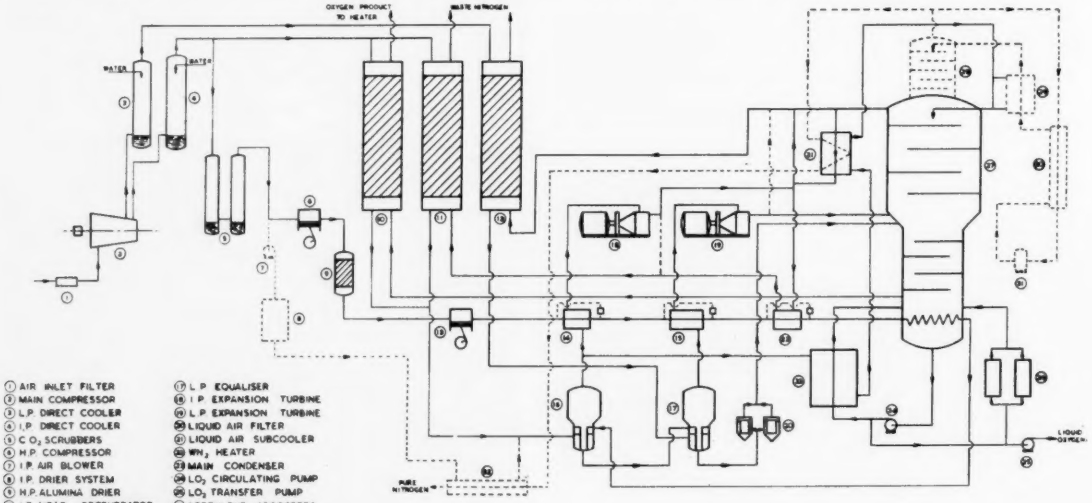

Fig. 8—Diagrammatic flowsheet of Rescol 'H' plant

turbine can also be used to reduce the time required to cool the plant after thawing.

Tonnage Oxygen Costs

The cost of production of tonnage oxygen varies with the scale of production, the cost falling as the size of the plant increases (Fig. 9). There are many factors which influence the capital and operating costs as these depend on the type of layout, extent of services to be provided, type of foundations, extent of storage and distribution requirements, power costs, etc. It is therefore difficult to give precise figures but the curve shown in the diagram should be taken as a guide to illustrate the variation in costs with a scale of production varying from 100 tons/day duty up to 300 tons/day duty. The cost data are based on the following figures, which should be accepted as the cost ex plant:

Power	1*d.* per kWh
Depreciation	15 years
Return on capital investment	15%
Cooling water	1s./1000 gal
Caustic soda	£2/ton
Annual operating time	8400 h

No allowance has been made for storage and distribution, including compression, and factory overheads have been eliminated as these are variable depending on the procedure used by the different companies.

Acknowledgment

The authors wish to express their thanks to The British Oxygen Co., Ltd., for the use of the drawings and illustrations which have been made available to them.

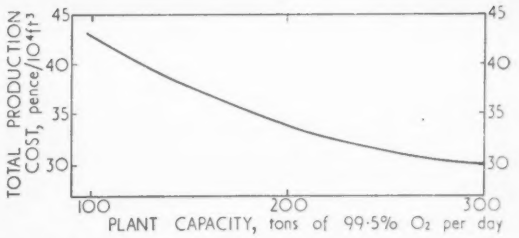

Fig. 9—Cost-of-production curve for power at 1*d.*/kWh

References

1. P. Coheur and H. Kosmider: *Trans. Amer. Inst. Min. Met. Eng.*, 1954, vol. 200, pp. 829–835.
2. W. P. Cashmore: *J. Iron Steel Inst.*, 1954, vol. 178, pp. 112–121.
3. J. S. Marsh: Yearbook of American Iron and Steel Institute, 1951, pp. 185–200.
4. M. W. Thring: *J. Iron Steel Inst.*, 1947, vol. 157, pp. 285–291.
5. M. W. Thring: *Ibid.*, 1954, vol. 178, pp. 165–169.
6. H. R. Fehling: *J. Inst. Fuel*, 1948, vol. 21, pp. 221–241.
7. M. W. Thring: *Iron Coal Trades Rev.*, 1948, vol. 157, pp. 1063–1071.
8. W. Jackson, R. Wogin, and R. Johnson: *Ibid*, vol. 171, pp. 889–896.
9. B. V. Sevruk, A. V. Leskov, and I. S. Marakhovskii: *Stal'*, 1955, No. 12, pp. 1074–1081.
10. A. V. Leskov: *Metallurg*, 1956, No. 1, p. 29.
11. S. R. Isaac: *Iron Coal Trades Rev.*, 1954, vol. 168, pp. 1479–1481.
12. A. J. Kesterton: *Ibid.*, 1954, vol. 168, p. 1480.
13. A. Jackson: *J. Iron Steel Inst.*, 1949, vol. 162, pp. 136–162.
14. D. F. Marshall: *Ibid.*, 1952, vol. 172, pp. 315–326.
15. E. Davis: *Iron Coal Trades Rev.*, 1956, vol. 172, pp. 987–988.
16. K. Heinrich: *Ibid.*, 1955, vol. 171, pp. 319–323.

A Study of Temper-Brittleness in Cr–Mn Steel containing Large Amounts of Molybdenum, Tungsten, and Vanadium

By A. E. Powers

SYNOPSIS

Data on the effect of molybdenum up to 2%, tungsten up to 4%, vanadium up to 1½%, and combinations of these elements, on the susceptibility to temper-brittleness of a Cr–Mn steel are presented. Strong interaction effects have been discovered when both molybdenum and vanadium are present in steel, resulting in much less susceptibility than when either element is present without the other. The results are discussed on the basis that susceptibility is controlled by the interaction energy for intergranular segregration of the solute alloying elements and by the diffusion rates of the segregating elements. 1368

Introduction

TEMPER-BRITTLENESS in ferritic steel has been under continual investigation for at least the past five decades; yet today it remains a most intriguing phenomenon, because, in spite of considerable investigation, a rigorous and clear description of its mechanism has not been possible. The purpose of this report is to present new data, which, it is hoped, will provide a deeper insight into the nature of the embrittlement. While the data are not sufficient to enable a comprehensive postulation of the mechanisms involved to be made, a brief and suggestive speculation is ventured. A review of the nature and characteristics of temper-brittleness will not be given,

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Table I
COMPOSITION AND HARDNESS OF STEEL

Designation	Composition, %							Brinell Hardness before Ageing
	C	Si	Mn	Cr	Mo	W	V	
Base	0·24	0·49	0·98	0·95				255
¼ Mo	0·26	0·44	1·02	0·95	0·50			262
¾ Mo	0·26	0·29	1·00	1·04	0·83			255
1 Mo	0·25	0·30	0·97	0·98	1·01			252
1½ Mo	0·24	0·41	0·99	1·03	1·51			256
2 Mo	0·27	0·40	1·04	0·94	2·00			246
½ W	0·22	0·40	0·98	0·98		0·50		251
1 W	0·23	0·20	1·00	0·98		0·97		258
1½ W	0·20	0·28	0·95	0·95		1·47		248
2 W	0·27	0·28	1·00	0·96		1·90		248
4 W	0·29	0·28	0·96	0·99		3·82		241
½ V	0·26	0·25	1·00	1·02			0·50	241
1 V	0·28	0·38	0·99	1·00			1·0	260
1½ V	0·25	0·20	0·97	1·04			1·5	269
½ Mo + 1 W	0·29	0·31	0·95	1·01	0·52	0·96		255
1 Mo + ½ V	0·29	0·35	0·97	1·01	0·97		0·54	262
1 Mo + 1 V	0·29	0·41	0·98	0·96	0·95		1·04	269

since this has been carried out excellently by Woodfine.[1]

MATERIAL AND PROCEDURE

Briefly, the susceptibilities were determined for a 1% Cr–1% Mn steel, to which had been added up to 2% molybdenum, up to 4% tungsten, up to 1½% vanadium, and several combinations of these elements. The 1% Cr–1% Mn base composition assured a reasonable degree of susceptibility before the other elements were added. While some, but not all, of the data on the molybdenum- and tungsten-containing alloys have been published elsewhere,[2] they are included here in entirety for continuity and clarity of this report.

The alloys investigated are listed in Table I. These sixteen alloys were cast as 55-lb ingots, from an induction furnace using 0·1% aluminium deoxidation. Slabs, ½ in. thick × 6 in. wide × 5 ft long, were forged from the ingots and subsequently normalized from 1700° F (925° C). The slabs were sliced into ½ × 6 × 2½-in. plates, from which **V**-notched Charpy specimens were eventually machined after heat-treating and ageing.

Since susceptibility to temper-brittleness is affected by hardness and austenite grain-size,[1] an attempt was made to keep these properties uniform in all alloys. Hardening was done by oil-quenching after ½ h at 2100° F (1150° C). Austenite grain-sizes averaged around A.S.T.M. 3 and 4, except in the ½% tungsten steel, which had an appreciably larger grain-size of about A.S.T.M. 1. The reason for this unintentionally large grain-size in the ½% tungsten steel may have been due to incomplete aluminium deoxidation. Each steel was tempered individually to attain a hardness of approximately 250 Brinell.

Embrittlement was done by ageing for 1000 h at temperatures ranging from 700° to 1050° F (370° to 565° C) in 50° F (28° C) intervals, to obtain a cross-section of the isothermal embrittlement diagram at 1000 h. Fracture transition-temperature curves were obtained for each embrittling treatment, using about twelve **V**-notched Charpy specimens for each curve.

RESULTS

Embrittlement of the Molybdenum- and Tungsten-Containing Alloys

A sample of the embrittlement curves for the 1000-h ageing is given in Fig. 1. The data are plotted as fracture transition-temperature at 50% brittle-fracture area of the broken Charpy specimen, against a function of the ageing temperature. The interrupted horizontal line represents the unembrittled transition-temperature based upon the testing of unaged specimens.

Figure 2 presents an assembly of the embrittlement curves for the molybdenum alloys—the Cr–Mn alloy containing 0, ½, ¾, 1, 1½, and 2% molybdenum; Fig. 3 contains the embrittlement curves for the 0, ½, 1, 1½, 2, and 4% tungsten alloys and also the ½% Mo + 1% W alloy. Figure 2 shows that the ¾% molybdenum alloy possesses least susceptibility, and that higher amounts of molybdenum produce as much or greater susceptibility than the molybdenum-free alloy.

In Fig. 3, the 1% tungsten alloy possesses least susceptibility, while larger amounts of tungsten appear to yield as much or more susceptibility than is found in the Cr–Mn base composition. The anomalously high embrittlement exhibited by the ½% tungsten alloy, possibly due to the unusually large grain-size of this alloy, is not regarded as being the normal behaviour of the alloy. The data on the 4% tungsten alloy confirm Vidal's conclusion that 3·8% of tungsten does not inhibit temper-brittleness.[3] It may be concluded that tungsten behaves in a manner similar to molybdenum in its effect upon temper-brittleness, when comparison is made on an atomic percentage basis.

The susceptibility of the ½% Mo + 1% W alloy, shown in Fig. 3, appears to be less at ageing temperatures below 1000° F (540° C) than a Cr–Mn alloy possessing an equivalent atomic percentage of either molybdenum (1%) or tungsten (2%) alone. This susceptibility of the combination alloy was also definitely lower than the simpler alloys after embrittling by a slow cooling operation. In other words, there appears to be an interaction effect between

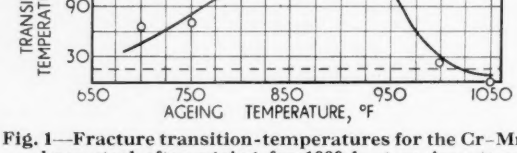

Fig. 1—Fracture transition-temperatures for the Cr–Mn base steel after ageing for 1000 h at various temperatures

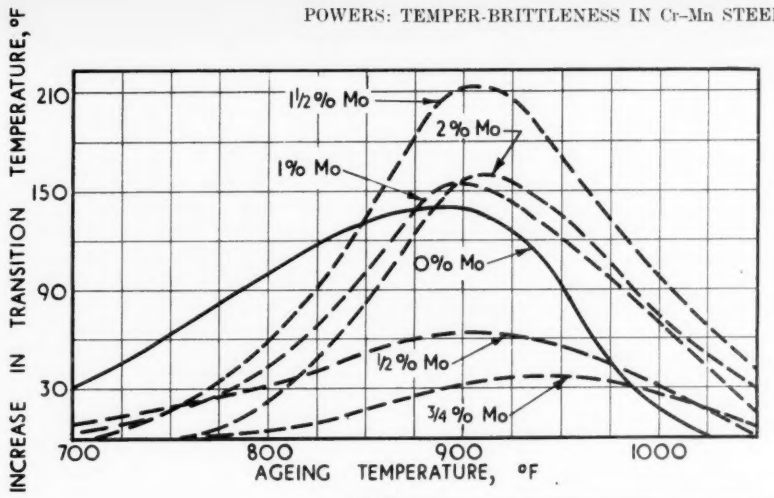

Fig. 2—Development of temper-embrittlement by molybdenum alloys after ageing for 1000 h

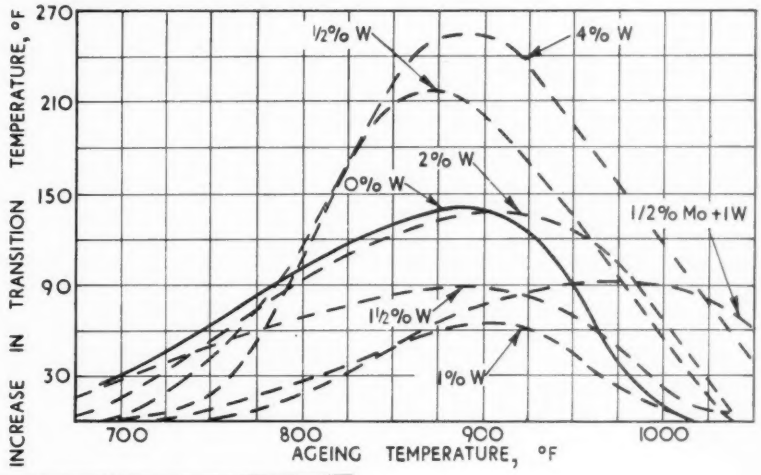

Fig. 3—Development of temper-embrittlement by tungsten alloys after ageing for 1000 h

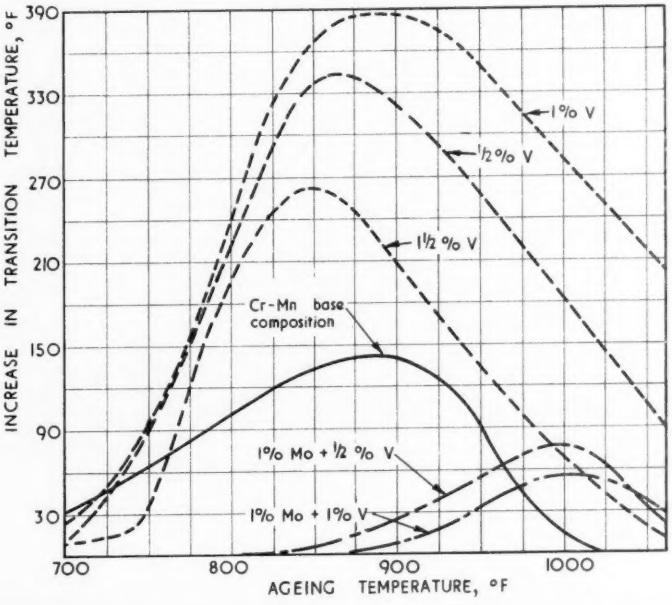

Fig. 4—Development of temper-embrittlement by V and Mo + V alloys ageing for 1000 h at various temperatures

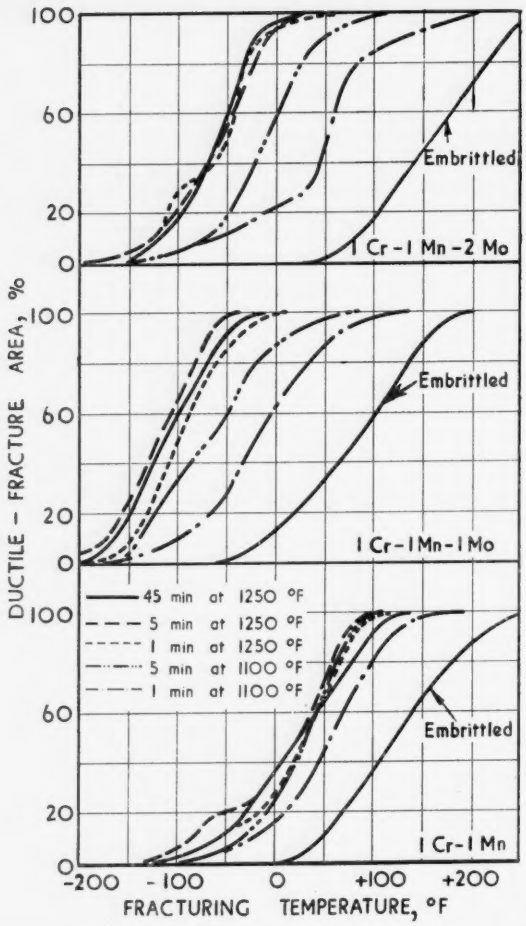

Fig. 5—Fracture transition-temperature curves for an embrittled steel after heating at 1100° and 1250° F in a lead bath

molybdenum and tungsten of advantage in adding the two elements in combination rather than either alone. Another unique characteristic of the ½% Mo + 1% W alloy is that the maximum embrittlement for 1000-h ageing occurs at about 975° F (525° C), whereas the Cr–Mn alloys, containing only molybdenum or tungsten, exhibit maximum embrittlement at the lower ageing temperatures of around 900° F (480° C).

Embrittlement of the Vanadium-containing Alloys

A compilation of the embrittlement curves for the vanadium-containing steels is given in Fig. 4. The great susceptibility of the Cr–Mn alloys containing ½, 1, and 1½% vanadium is noteworthy. Embrittlement is greatest in the 1% vanadium alloy and extends to ageing temperatures above 1100° F (595° C). The embrittlement in the 1½% vanadium alloy is less than in the alloys containing ½% and 1% vanadium.

The Cr–Mn alloys containing 1% Mo + ½% V and 1% Mo + 1% V show unexpected behaviour. Here the simultaneous addition of two alloying elements, molybdenum and vanadium, results in very little susceptibility; whereas, if 1% or more of either element is added alone to Cr–Mn steel, considerable susceptibility will be obtained. Although it does not inhibit the embrittlement of the Cr–Mn material, 1% molybdenum strongly inhibits the embrittling action of high vanadium content; that is, the susceptibility of a Cr–Mn steel with 1% molybdenum may be appreciably reduced by the addition of ½% or more of vanadium. There appears to be a very strong interaction effect between molybdenum and vanadium. Of further note is the relatively high temperature of 1000° F (540° C) for maximum embrittlement in these Mo + V alloys. A high peaking temperature was seen with one other complex alloy, the Cr–Mn alloy with ½% molybdenum and 1% tungsten.

Dissipation of Temper-brittleness

Observations were made on the rate at which temper-brittleness can be displaced by heating to 1100° and 1250° F (595° and 675° C). Rough blanks for Charpy specimens of the 1% Cr–1% Mn alloy with 0, 1, and 2% molybdenum added were embrittled by a 16-day step-cooling procedure,* and then heated in a lead bath at 1100° and 1250° F for 1, 5, and 45 min total time. To promote a high heating rate, the Charpy blanks were preheated to 900° F and then individually dipped into the lead bath at the intended temperature. Thermocouples attached to a few trial specimens showed that the temperature rose to within 20° F of the intended temperature within 30 s. The specimen temperature of 1250° F was reached in 3 min and of 1100° F in 1 min.

Figure 5 shows the transition-temperature curves, using the fracture-appearance measurements, for heating times of 1, 5, and 45 min at 1250° F (675° C), and times of 1 and 5 min at 1100° F (595° C). While the treatment of 5 min at 1100° F has essentially eliminated all temper-brittleness in the 1% Cr–1% Mn alloy, it has not been entirely sufficient to do this with the Cr–Mn alloys containing 1% and 2% molybdenum. It may therefore be concluded that when molybdenum is present temper-brittleness is removed more slowly at temperatures above the embrittling range.

Figure 5 also clearly illustrates the high susceptibility of alloys containing 1% and 2% molybdenum without vanadium.

DISCUSSION

Currently, one of the more prominent theories for the mechanism of temper-brittleness is that the phenomenon is due to the intergranular segregation of solute atoms during ageing within, or slow cooling through, the embrittling temperature range. [2, 4, 5, 6]

* Heated to 1100° F, cooled to 1075° F, held at this temperature for 24 h, cooled to 1050° F, held for 24 h, and so on, until a temperature of 700° F is reached 16 days later. This treatment was found to produce as much embrittlement as 1000 h at 900° F.[2]

This segregation, termed 'equilibrium segregation' by McLean and Northcott,[6] is thought to reduce the cohesive strengths at lattice discontinuities, particularly at what were formerly the austenitic grain-boundaries.

The best physical evidence so far for intergranular segregation of solute atoms as a cause of temper-brittleness is the selective etching of the former austenitic grain-boundaries of an embrittled steel. Several recent and thorough electron-microscopic examinations[4, 7] have revealed no pertinent precipitation, and only a uniform etching of grain-boundaries, the nature of which has led Perryman[13] to suggest that the embrittled grain-boundaries are cathodic to the grains.

Thomas and Chalmers[8] have shown evidence by autoradiographic means of the intergranular segregation of α-emitting polonium in lead. The appearance of significant segregation began only with grain orientation differences greater than 15°. The observation that the equilibrium degree of segregation diminished with increasing temperature corresponds to the observation that the equilibrium degree of temper-embrittlement also diminishes with increasing temperatures above 1000° F (538° C). A negative temperature-coefficient of adsorption is indicated here.

A recent attempt[9] to observe intergranular micro-segregation of radio-active phosphorus in steel after temper-embrittling proved to be unsuccessful, presumably because of insufficient resolution conferred by the energetic β-rays of phosphorus 32.

McLean[10] has given evidence to indicate that a mere intergranular segregation of antimony atoms in copper, rather than the precipitation of a separate phase, can bring about considerable intergranular embrittlement. Other indirect evidence for the grain-boundary segregation of solute atoms has been found in alloys involving bismuth in copper,[11] tin in copper,[12] iron in aluminium,[13] magnesium in aluminium,[14] aluminium in brass,[15], and phosphorus in brass.[16] This intergranular segregation is thought to occur in order to relieve the strain energy produced in the lattice by solute atoms that are larger or smaller than the solvent atoms.

This strain-energy mechanism, however, may be modified by interatomic forces. The concentration of solute atoms at grain-boundaries means that a solute atom A, in a solvent B, has a greater number of other solute atoms as its nearest neighbours than when it was situated in the crystalline lattice. If there is a tendency for the A atoms to be more energetically attracted to each other than to B atoms in the crystalline lattice or, in other words, a tendency to form more A–A pairs than would be expected for a random solution, grain-boundary segregation may be accentuated. Limited solubility is the end result of the tendency for the pairing of like atoms.

Conversely, strong attractions between unlike atoms such that $vAB < \frac{vAA + vBB}{2}$ should tend to discourage the clustering of like solute atoms and their concentration in grain-boundaries. This avoidance of clustering of like atoms is usually observed in systems exhibiting short-range and long-range ordering. It is interesting in this connection that the elements cobalt, nickel, silicon, and aluminium, when present by themselves in carbon-containing ferrite, do not promote temper-brittleness. These four elements are known to exhibit ordering tendencies in solid solutions of iron.

When a second solute element C is added to solvent B and solute A, the overall results are complex. For example, the addition of nickel to a manganese-containing steel will augment the embrittlement caused by manganese.[17] On the other hand, the data in this paper show that molybdenum and vanadium, two elements promoting embrittlement when not added in combination, promote very little susceptibility when present together in steel. To gain some idea of the nature of these interaction effects the 1000-h embrittlement curves in Figs. 2, 3, and 4 should be examined closely.

When ageing at temperatures below that which will produce the most rapid rate of embrittlement (below 900° F), embrittlement appears to proceed at a rate governed by the diffusion of substitutional alloying elements. The activation energy for embrittlement can be found from the slope of the iso-embrittlement curves. Using the isothermal embrittlement diagram of Carr *et al.*[18] for SAE 3140 with the relation,

$$\ln\left(\frac{t_1}{t_2}\right) = \frac{Q}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \quad \ldots\ldots(1)$$

the activation energy has been found to be between 46,000 and 60,000 cal/mole. This compares with the reported values of 73,200 and 59,800 cal/mole for the self-diffusion of α-iron,[19, 20] and 57,700 cal/mole for the diffusion of molybdenum in α-iron.[21] A complementary conclusion is that the development of embrittlement does not seem to be governed by the diffusion of carbon.

At temperatures above that required to produce maximum embrittlement (above 950° F), embrittlement develops rapidly but soon reaches an equilibrium value. Apparently an equilibrium degree of segregation is reached that is a balance between the interaction energy V, moving the atoms to the grain boundaries, and the thermal energy kT which tends to disperse the atoms.

A relation often quoted for non-saturated atmospheres is the Maxwell–Boltzmann law,

$$C = ce^{-\frac{V}{kT}} \quad \ldots\ldots(2)$$

where c is a constant, while McLean has offered the relation

$$C_B = \frac{Ace^{-\frac{Q}{RT}}}{1 + Ace^{-\frac{Q}{RT}}} \quad \ldots\ldots(3)$$

for grain-boundary concentrations approaching saturation.[5]

Accordingly, it is probable that the effect of alloying additions in causing temper-brittleness to be retained at higher temperatures is the result of an increase in the interaction energy V. The data in Figs. 2, 3, and 4 show that all additions of molybdenum, tung-

sten, and vanadium appear to increase this interaction energy. Even the $\frac{1}{2}$% and $\frac{3}{4}$% Mo alloys lose their embrittlement at temperatures higher than those for the Cr–Mn base alloy. The Cr–Mn–V alloys of Fig. 4 apparently have the highest value of interaction energy, since embrittlement is not dissipated until temperatures of 1100° F (595° C) and above are reached. The complex alloys containing molybdenum and vanadium (Fig. 4) and molybdenum and tungsten (Fig. 3) also exhibit embrittlement at relatively high temperatures. Apparently there are interactions between the molybdenum, tungsten, and vanadium atoms resulting in larger interaction energies for intergranular segregation.

The lower susceptibilities of the molybdenum- and tungsten-containing alloys at temperatures of 800° F (425° C) and below appear to result from a slower rate of embrittlement. This suggests that the diffusion rates of the embrittling elements are reduced as molybdenum and tungsten are added. The identity of the embrittling elements is not known. The demonstrated slower rate of dissipation of temper-brittleness of the molybdenum-containing alloys at temperatures of 1100° and 1250° F (595° and 675° C) (Fig. 5) is another indication that slower diffusion rates are associated with the presence of molybdenum.

At temperatures below 900° F (480° C), the complex Cr–Mn–Mo–W and Cr–Mn–Mo–V alloys show evidence of very slow development of temper-brittleness, while at higher temperatures they exhibit high interaction energies. For example, these alloys suffer practically no embrittlement at 900° F (480° C) —the temperature of optimum embrittlement for the less complex alloys—yet they require temperatures as high as 1100° F (595° C) for the dissipation of embrittlement, which develops most rapidly at 1000° F (538° C). A strong interaction effect between the molybdenum and vanadium atoms is indicated.

Perhaps remotely related is an interaction effect between molybdenum and vanadium on the creep-strength and secondary hardening of ferritic steel.[22] In ferritic steel it is possible to attain greater creep-strength with combinations of molybdenum and vanadium than with any amount of molybdenum alone or vanadium alone, up to limit of the γ-loop. Likewise, maximum secondary hardening occurs at a higher tempering temperature when molybdenum and vanadium are added in combination rather than either alone.

CONCLUSIONS

Data for a 1% Cr–1% Mn steel are presented, showing that molybdenum and tungsten are embrittling when present in amounts of over $\frac{3}{4}$% and 1% respectively. Vanadium in the absence of molybdenum is intensely embrittling; however, when molybdenum and vanadium are added together in amounts of $\frac{1}{2}$% and over, susceptibility is greatly reduced. This behaviour is ascribed to interaction effects between the molybdenum and vanadium atoms.

Temper-brittleness is described as an ' equilibrium segregation ' of solute atoms towards lattice discontinuities, primarily as the result of lattice straining by misfitting solute atoms. The segregation mechanism is thought to be modified by interatomic attractive forces.

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References

1. B. C. Woodfine: *J. Iron Steel Inst.*, 1953, vol. 173, pp. 229–239.
2. A. E. Powers: *Trans. Amer. Soc. Metals*, 1956, vol. 48, pp. 149–164.
3. G. Vidal: *Rev. Met.*, 1945, vol. 42, pp. 149–155.
4. B. C. Woodfine: *J. Iron Steel Inst.*, 1953, vol. 173, pp. 240–255.
5. D. McLean: *Metal Treatment and Drop Forging*, 1956, vol. 23, No. 125, pp. 55–61.
6. D. McLean and L. Northcott: *J. Iron Steel Inst.*, 1948, vol. 158, pp. 169–177.
7. W. C. Hagel: Unpublished work, 1955.
8. W. R. Thomas and B. Chalmers: *Acta Met.*, 1955, vol. 3, pp. 17–21.
9. A. E. Powers: Unpublished work, 1955.
10. D. McLean: *J. Inst. Metals*, 1952, vol. 81, pp. 121–125.
11. L. E. Samuels: *Ibid.*, 1949–50, vol. 76, pp. 91–101.
12. E. C. W. Perryman: *Trans. Amer. Inst. Min. Met. Eng.*, 1953, vol. 197, pp. 906–910; *J. Met.*, 1953, vol. 5, July.
13. E. C. W. Perryman: *Trans. Amer. Inst. Min. Met. Eng.*, 1953, vol. 197, pp. 911–917; *J. Met.*, vol. 5, July.
14. V. A. Phillips, O. J. Swain, and R. Eborall: *J. Inst. Metals*, 1952–53, vol. 81, pp. 625–646.
15. E. C. W. Perryman: *Ibid.*, 1955, vol. 83, pp. 369–377.
16. H. M. Miekk-Oja: *Ibid.*, 1951–52, vol. 80, pp. 569–576.
17. R. Hultgren and J. Chuan Chang: *Trans. Amer. Soc. Metals*, 1954, vol. 46, pp. 1298–1317.
18. F. L. Carr, M. Goldman, L. D. Jaffe, and D. C. Buffum: *Trans. Amer. Inst. Min. Met. Eng.*, 1953, vol. 197, p. 998; *J. Met.*, 1953, vol. 5, August.
19. C. E. Birchenall and R. F. Mehl: *Trans. Amer. Inst. Min. Met. Eng.*, 1950, vol. 188, pp. 144–149; *J. Met.*, 1950, vol. 2, Jan.
20. F. S. Buffington, I. D. Bakalar, and M. Cohen: " The Physics of Powder Metallurgy," chap. 6, pp. 92–107: 1951, New York, McGraw-Hill Book Co.
21. J. L. Ham: *Trans. Amer. Soc. Metals*, 1945, vol. 35, pp. 331–361.
22. A. E. Powers: *Trans. Amer. Inst. Min. Met. Eng.*, 1956, vol. 206, pp. 1373–1377; *J. Met.*, 1956, vol. 8, Oct.

A Thermodynamic Study of $FeO–Fe_2O_3–SiO_2$, $FeO–Fe_2O_3–P_2O_5$, and $FeO–Fe_2O_3–SiO_2–P_2O_5$ Molten Systems

By

E. T. Turkdogan

and

Patricia M. Bills

SYNOPSIS

The melts $FeO–Fe_2O_3–SiO_2$, $FeO–Fe_2O_3–P_2O_5$, and $FeO–Fe_2O_3–SiO_2–P_2O_5$ have been equilibrated with carbon-dioxide–carbon-monoxide mixtures at 1550° C over a wide composition range. Throughout the systems, increasing silica or phosphorus pentoxide or both decreases the Fe^{+++}/Fe^{++} iron ratio appreciably, the latter oxide being more effective than silica. Existing data on the solubility of silica in molten iron oxides have been extended to 1550°C at various p_{CO_2}/p_{CO} ratios. The results of this work together with the available data permit the construction of curves relating the Fe^{+++}/Fe^{++} ratio to silica and phosphorus pentoxide concentrations for p_{CO_2}/p_{CO} ratios from 75·0 down to very low values where melts are in equilibrium with liquid iron. 1407

Introduction

WORK HAS IN THE PAST been done to determine the oxygen potential of slags containing iron oxide. Herty[1] and Körber and Oelsen[2] determined the solubility of oxygen in molten iron in equilibrium with almost pure iron oxide. Later, Chipman and Fetters[3, 4] and Taylor and Chipman[5] redetermined this solubility by improved experimental techniques and the values obtained by them have since proved to be reliable. These authors[4, 5] also measured the change in oxygen solubility with slag composition and evaluated the activity of ferrous oxide in $CaO–MgO–FeO–SiO_2$ slags over a wide temperature and composition range. White[6] measured the dissociation pressure of ferric oxide into lower oxides of iron in simple and complex solid and in liquid slags at temperatures up to about 1650° C under oxygen pressures ranging from 0·02 to 1·0 atm. In more recent years, Darken and Gurry[7, 8] made an extensive study of the pure iron–oxygen system within the range 1100–1600° C by equilibrating the oxides of iron with various gases of known oxygen potential. These authors[9] subsequently determined the dissociation pressure of ferric oxide in $CaO–FeO–Fe_2O_3$ and $MnO–FeO–Fe_2O_3$ ternary melts at several oxygen pressures and at about 1600° C. Schuhmann and Ensio[10] and Michal and Schuhmann[11] studied the state of equilibrium in the $FeO–Fe_2O_3–SiO_2$ system saturated with γ-iron or silica or both under low oxygen potentials and within the temperature range 1250–1350° C. Work carried out by Larson and Chipman[12] deals mainly with similar measurements in the $CaO–FeO–Fe_2O_3$ and $CaO–FeO–Fe_2O_3–SiO_2$ systems at 1550° C.

The general conclusions to be drawn from the work mentioned above may be summarized as follows:

(i) The activities of ferrous and ferric oxides in simple and complex slags deviate from Raoult's law in varying degrees.

(ii) The ratio Fe^{+++}/Fe^{++} increases with the oxygen potential for a given temperature and slag composition, and decreases with increasing temperature for a given partial pressure of oxygen and slag composition.

(iii) For a given temperature and oxygen potential, the Fe^{+++}/Fe^{++} ratio increases with the concentration of BaO, CaO, MgO, and MnO, in that order, and decreases with TiO_2 and SiO_2. In liquid iron–calcium silicates, Fe^{+++}/Fe^{++} increases with increasing CaO/SiO_2 ratio. This is associated with the fact that in slags rich in basic oxides the trivalent iron forms oxyacid radicals, i.e. ferrites, which lower the activity coefficient of ferric iron. Furthermore, at high basicities interaction between ferrous ions and Si–O oxyacid anions is reduced, resulting in an increase in the activity coefficient of ferrous iron. Thus the overall effect is an increase in Fe^{+++}/Fe^{++} ratio with basicity. When the acidity increases the reverse argument will apply.

Although the work carried out by Larson and Chipman[12] covers a range of slag and gas compositions in the systems $CaO–FeO–Fe_2O_3$, $MgO–FeO–Fe_2O_3$, and $CaO–FeO–Fe_2O_3–SiO_2$, these results cannot be applied to more complex slags which contain a number of other oxides in varying proportions such as are encountered in ferrous metallurgical processes. It was therefore considered desirable that more work should be undertaken to determine the oxygen potential of simple and complex slags which have not so far been investigated in detail. As a preliminary, work on the systems $FeO–Fe_2O_3–SiO_2$, $FeO–Fe_2O_3–P_2O_5$, and $FeO–Fe_2O_3–SiO_2–P_2O_5$ was undertaken.

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EXPERIMENTAL

Apparatus and Procedure

The experimental method employed was very similar to that of Darken and Gurry[7]; that is, a sample of about 0·2 g of liquid slag, contained in a platinum crucible, was equilibrated with a mixture of carbon dioxide and carbon monoxide of known composition, and analysed after quenching.

The vertical furnace consisted of a recrystallized alumina tube, wound with molybdenum wire, 30 in. long by 2 in. o.d., fixed inside a gastight metal casing through which cracked ammonia was circulated. A recrystallized alumina reaction tube, 36 in. long by 1 in. i.d., previously tested for vacuum tightness at room temperature, was held within the furnace, and a control thermocouple was placed between the two alumina tubes and connected to a potentiometer-type on–off controller to actuate a mercury switch. The temperature of the hot zone was measured and found to be within $\pm 3°$ C over the 1·5-in. length.

The water-cooled upper end of the reaction tube carried a rubber bung through which a $\frac{3}{16}$-in. bore recrystallized alumina sheath and a $\frac{3}{8}$-in. bore recrystallized alumina tube were inserted. The latter tube served as a gas inlet and positioned the crucible in the centre of the furnace. The tip of the thermocouple sheath and the platinum crucible ($\frac{1}{2}$ in. dia. by $\frac{1}{2}$ in. depth) were placed side by side; in this way the temperature of the melt could be measured. The top of the gas inlet tube was connected to a glass **T**-piece by means of rubber pressure tubing. The side arm of the **T**-piece was connected to the gas-train. The vertical arm carried another piece of rubber pressure tubing through which passed a platinum wire supporting the crucible, the wire being held in position by a means of a screw clip. The upper end of this second piece of rubber tubing could be blocked by a glass rod to prevent leakage of gas through the clipped part of the tube.

The lower end of the reaction tube carried a rubber bung through which a water-cooled copper block, combined with a gas outlet, was inserted. When the sample was ready to be quenched, the screw clip holding the suspension wire was released and the crucible fell on to the copper block. Initially, quenching the samples in a pool of mercury had been tried, but invariably large quantities of mercury were trapped in the slag, and this contamination made the analyses unreliable. Quenching on the water-cooled copper block, however, was found to be very satisfactory.

Gas-train and Gas Analysis

A cylinder of carbon dioxide was used as the source of both carbon dioxide and carbon monoxide. Carbon dioxide was first purified by passing it over copper at 500° C to remove oxygen, then through magnesium perchlorate to remove water vapour. The CO was prepared from this gas by passing through charcoal at 1100° C, the charcoal being contained in a mullite tube inside a platinum wire-wound furnace. When the charcoal was renewed, the furnace was evacuated continuously for 24 h at 600–700° C, and the charcoal was not exposed to the atmosphere after this vacuum purification. The reaction between carbon and CO_2 at 1100° C goes almost to completion; residual CO_2 and water vapour were absorbed by passage through regularly renewed columns of soda asbestos and magnesium perchlorate. The purified CO_2 and CO were then passed into their respective flowmeters which had been previously calibrated. The metered gases were mixed by passage through a column of glass beads and then led into the reaction tube. To keep the composition of the gas mixture constant through the experiment, the usual rate-controlling flowmeters were used.

The gas leaving the reaction chamber was analysed periodically to see if it had the same composition as the incoming gas, i.e. if equilibrium had been established. This had to be done without upsetting the gas flow through the reaction tube, and was accomplished in the following way. A flask of 250 ml capacity was connected as a by-pass to the gas outlet. Before the analysis the gas was allowed to flow through the flask and then through an oil bubbler. When an analysis was required, the gas flow was diverted through another branch of the outlet. Then dried, oxygen-free nitrogen was admitted to sweep out the contents of the flask and its connecting tubes into the absorption-train for CO_2 and CO analysis, which was of the conventional type. The CO_2 was first absorbed by soda asbestos and magnesium perchlorate, the remaining CO was then passed through copper oxide at 500° C to convert it to CO_2 which in turn was absorbed. From the weight gains of the absorbents, the ratio p_{CO_2}/p_{CO} was derived.

Slag Analysis

To prevent any oxidation of ferrous iron to ferric iron, the sample, weighing about 0·2 g, was crushed only coarsely, and not ground. It was then dissolved in a mixture of HF and HCl under a stream of nitrogen. The lower portion of the test tube holding the sample was immersed in an oil bath at about 120° C. After the sample had dissolved, the contents of the test tube were cooled in nitrogen and the solution was made up to 250 ml in a graduated flask and aliquot portions were taken for the determination of ferrous iron, total iron, and phosphate ions.

The ferrous iron was always determined immediately after dissolving the slag to prevent any oxidation to the ferric state. This determination was carried out by titration with 0·01N potassium dichromate in the presence of phosphoric and sulphuric acids and using sodium diphenylamine sulphonate as indicator. Total iron was estimated in the same way after reduction with stannous chloride. The difference between these two titrations gave the amount of ferric iron. When the concentration of the latter was less than about 2% in the slag, it was determined directly in the following way. The sample was dissolved in concentrated HCl containing about 30% HF in a platinum crucible in an atmosphere of nitrogen at 125° C. When cold, the solution was diluted to 250 ml and 50 ml portions were taken for duplicate ferric iron analyses. 50 ml of saturated boric acid solution was added to convert any fluoride ions to fluoroborate, since fluoride interferes with the colour formation of the indicator, ammonium thiocyanate. Then 10 ml of HCl and 10 ml of 10% solution of thiocyanate

were added. The solution was then titrated with 0·0015% titanium trichloride solution (kept in an atmosphere of hydrogen) until the red colour disappeared. The titanium trichloride solution was standardized immediately before use. The agreement between duplicate titrations had a maximum variation of 0·5% of the ferric iron present.

To determine the phosphate ion in the slag, an aliquot of the original solution was heated to dryness with concentrated HNO_3 to separate any silica remaining in the solution; the residue was then taken up in dilute HNO_3 and the phosphate was precipitated as ammonium phosphomolybdate. After filtering and washing, the acid-free precipitate was dissolved in a known quantity of standard caustic soda solution and then back-titrated with HCl. Duplicate estimations agreed within $\pm 0{\cdot}5\%$ of the total amount present.

Since the sample was dissolved in HF, its silica content was determined by difference after the concentrations of the other components had been found. This is justified for the following reasons:

(i) The other constituent oxides could be determined accurately
(ii) The samples were not contaminated during the experiment
(iii) Occasional samples when analysed for silica gave a total of $100 \pm 0{\cdot}5\%$.

Materials

Silica: Natural pure quartz crystals were crushed to pass through a 120 mesh sieve, washed with *aqua regia* and water, and dried at 120° C.

Ferric oxide: This was prepared from Analar ferric sulphate by heating at 1000° C; both the weight loss obtained and analysis for iron gave the formula Fe_2O_3.

Ferrous oxide: The ' ferrous oxide ' was prepared from ferric oxide and pure electrolytic iron mixed in the right proportions and heated at 1000° C in dry, oxygen-free nitrogen.

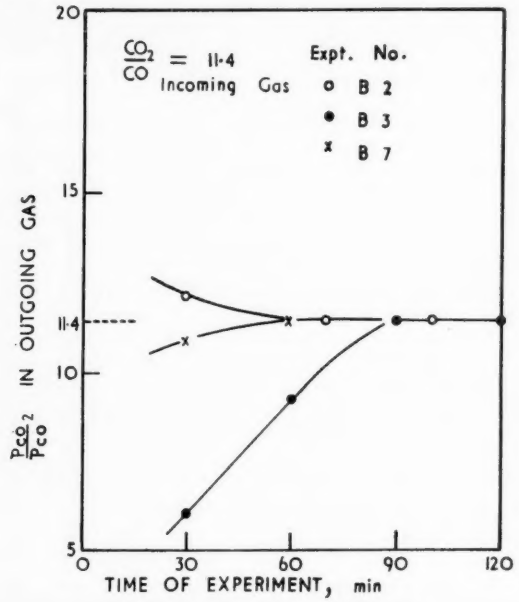


Fig. 1—Approach to equilibrium

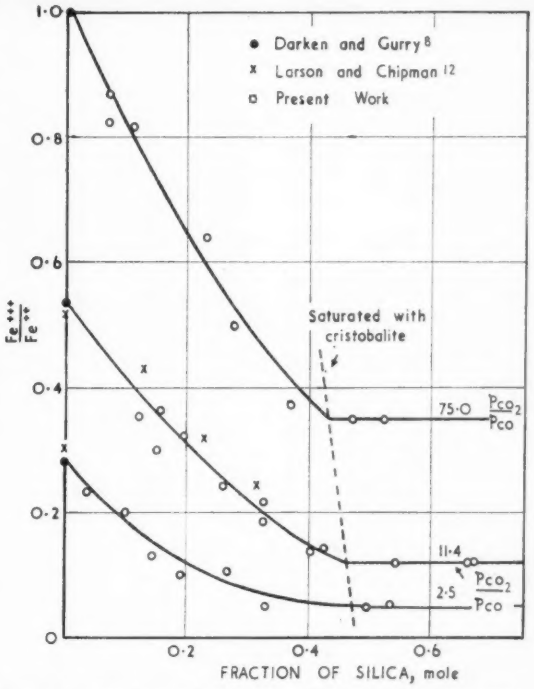


Fig. 2—Variation of the Fe+++/Fe++ ratio with gas and slag composition at 1550° C in the FeO–Fe_2O_3–SiO_2 system

Ferrous phosphate: This was prepared by heating in nitrogen a mixture of Analar di-ammonium hydrogen phosphate and ferrous oxide, in the right proportions, at about 800° C. The weight loss and the analysis corresponded to the formation of tri-ferrous phosphate.

RESULTS

Attainment of Equilibrium

In an investigation of this kind it must be established that at the termination of the experiment the slag and gas phases are in a state of equilibrium. In a few preliminary experiments the outgoing gas was analysed about every 30 min over a period of 2 h. As indicated by the results in Fig. 1, equilibrium was established within 1–1·5 h; this is indicated by the identical composition of the incoming and outgoing gas.

In all the subsequent experiments the time of reaction was 2 h and the outgoing gas was always analysed twice, with an interval of 30 min, during the last hour of the experiment, and in all cases the composition of the incoming and the outgoing gas was found to be within $\pm 0{\cdot}2\%$.

Another important point to bear in mind is thermal diffusion in the gaseous phase. A total gas flow of 150 ml/min was used throughout this work. The gas flow used by Larson and Chipman[12] was also of the same order. To make sure that thermal diffusion was absent from the present experiments, a strip of pure iron foil was held at 1350° C in the furnace at various p_{CO_2}/p_{CO} ratios, the total flow of the gas

Table I—DATA ON EQUILIBRIUM MEASUREMENTS AT 1550° C

No.	FeO, %	Fe_2O_3, %	SiO_2, %	Fe^{+++}/Fe^{++}	N_{SiO_2}	p_{CO_2}/p_{CO}	No.	FeO, %	Fe_2O_3, %	SiO_2, %	P_2O_5, %	Fe^{+++}/Fe^{++}	N_{SiO_2}	$N_{P_2O_5}$	p_{CO_2}/p_{CO}
A 1	48·70	47·07	4·23	0·869	0·068	75·0	D 1	36·47	1·038	62·49		0·0256	0·675		0·324
2	49·82	45·87	4·31	0·828	0·068	,,	2	46·70	1·504	51·80		0·0290	0·567		0·191
3	48·91	44·42	6·67	0·818	0·104	,,	3	46·30	1·037	52·66		0·0201	0·574		0·089
4	48·99	34·83	16·18	0·639	0·230	,,	4	43·18	0·949	55·87		0·0198	0·605		0·083
5	51·22	28·40	20·38	0·501	0·276	,,	*5	40·41	1·073	58·52		0·0239	0·632		0·179
6	50·41	20·87	28·72	0·372	0·365	,,	*6	41·32	1·019	57·66		0·0222	0·623		0·151
7	44·38	17·16	38·47	0·348	0·469	,,	†7	45·09	1·616	53·29		0·0322	0·582		0·653
8	40·82	15·82	43·36	0·349	0·519	,,									
							E 1	53·07	9·51	0	37·44	0·161	0	0·248	75·0
B 1	65·43	25·86	8·71	0·355	0·119	11·4	2	54·09	20·59	5·99	19·33	0·342	0·092	0·122	,,
2	66·53	22·24	11·23	0·301	0·149	,,	3	53·51	21·85	8·80	15·84	0·367	0·129	0·098	,,
3	63·26	25·50	11·24	0·362	0·153	,,	4	53·05	19·58	11·80	15·57	0·332	0·168	0·094	,,
4	62·07	23·31	14·62	0·321	0·194	,,									
5	62·81	16·85	20·34	0·242	0·257	,,	F 1	61·99	6·79	0	31·22	0·090	0	0·220	11·4
6	59·40	14·29	26·31	0·216	0·323	,,	2	57·83	6·08	5·25	30·84	0·095	0·076	0·189	,,
7	60·97	12·68	26·35	0·186	0·326	,,	3	58·57	5·75	12·38	23·30	0·088	0·169	0·164	,,
8	57·16	8·42	34·42	0·133	0·403	,,	4	60·64	17·63	13·32	8·41	0·261	0·179	0·048	,,
9	55·18	8·72	36·09	0·143	0·422	,,	5	54·16	6·09	16·00	23·75	0·101	0·217	0·136	,,
10	45·98	6·05	47·97	0·119	0·541	,,	6	48·33	4·64	26·03	21·00	0·086	0·337	0·115	,,
11	34·91	4·64	60·45	0·119	0·661	,,	7	41·99	3·43	39·55	15·03	0·073	0·481	0·077	,,
12	34·47	4·67	60·86	0·122	0·666	,,									
							G 1	56·55	2·96	0	40·49	0·047	0	0·262	2·5
C 1	77·55	19·96	2·49	0·231	0·033	2·5	2	74·81	19·64	0	5·55	0·236	0	0·033	,,
2	75·41	16·74	7·85	0·199	0·102	,,	3	69·65	7·23	7·08	16·04	0·093	0·095	0·091	,,
3	77·31	11·22	11·47	0·130	0·143	,,	4	60·93	2·93	10·35	25·79	0·044	0·141	0·149	,,
4	76·13	8·21	15·66	0·097	0·190	,,	5	63·49	4·08	12·55	19·98	0·058	0·166	0·111	,,
5	70·00	8·11	21·89	0·104	0·262	,,	6	61·80	5·55	18·75	13·90	0·081	0·239	0·075	,,
6	68·00	3·72	28·28	0·049	0·327	,,									
7	53·36	2·69	43·95	0·045	0·491	,,									
8	49·41	2·90	47·69	0·053	0·529	,,									

* At 1450° C † At 1600 C°

mixture being 150 ml/min. After each experiment, the iron foil was examined visually for any signs of the appearance or disappearance of an oxide film. The gas ratio, to form wüstite in equilibrium with γ-iron, determined in this way was 0·289 which is concordant with 0·287 derived from the results of Darken and Gurry.[8]

Although under reducing conditions slags containing iron oxide are known to attack platinum crucibles at elevated temperatures, in a series of experiments using $p_{CO_2}/p_{CO} = 75·0$ or 11·4, the wear on the platinum crucibles was not great, and in fact, one crucible could be used satisfactorily for about six experiments, each lasting 2 h. In melts with $p_{CO_2}/p_{CO} = 2·5$, however, a crucible was used for three experiments only.

FeO–Fe_2O_3–SiO_2 Ternary System

The proportions of the divalent and trivalent iron are affected appreciably by the slag composition and the oxygen potential of the system. This is illustrated in Fig. 2 where the values of Fe^{+++}/Fe^{++} ratios are plotted against the mole fraction of silica for three values of gas ratio from the results given in Table I. The intercepts of the curves with the ordinate give the Fe^{+++}/Fe^{++} ratios in the iron–oxygen binary system at three different p_{CO_2}/p_{CO} ratios evaluated from the results of Darken and Gurry.[8] For comparison, the data of Larson and Chipman[12] are also included in Fig. 2. The points lying on the horizontal lines are from silica-saturated slags, and the points of intersection of the curves give the concentrations of the silica solubility at 1550° C at different partial pressures of oxygen. The dotted line is derived from other data (Fig. 7) and it will be seen that this line indicating the formation of cristobalite is concordant with the present results. In the case of melts in equilibrium with $p_{CO_2}/p_{CO} = 2·5$, there is no definite change in the slope of the curve at silica saturation; this curve, however, is drawn to meet the horizontal line tangentially and the value of N_{SiO_2} at this point of contact may be taken to be 0·475.

As mentioned previously, White[6] measured the oxygen dissociation pressure of various ternary and quaternary systems containing iron oxide. From his results on the ternary system FeO–Fe_2O_3–SiO_2, the values of Fe^{+++}/Fe^{++} and p_{CO_2}/p_{CO} ratios were calculated, and as shown in Fig. 3, the Fe^{+++}/Fe^{++} iron ratio decreases with an increasing mole fraction of silica. It should be noted that for a given partial pressure of oxygen, e.g. $p_{O_2} = 0·2$ atm, the value of Fe^{+++}/Fe^{++} decreases with a rise in temperature, and for a given temperature and concentration of silica, the Fe^{+++}/Fe^{++} iron ratio decreases with a decrease in oxygen potential of the system.

Silica saturation experiments were carried out by using silica instead of platinum crucibles. In this way it was possible to obtain some equilibrium data at lower oxygen potentials. These results, together with those given by the points of intersection of the curves in Fig. 2, are plotted in Fig. 4. In this diagram are also included the results of White[6] (Fig. 3), Michal and Schuhmann,[11] and the gas ratio recommended by Darken[13] for the quintuple point where γ-iron, silica, fayalite, and molten silicate are all present at equilibrium; the temperature and composition of this point were taken from Bowen and Schairer.[14]

It is interesting to note that the relationship in Fig. 4 appears to be independent of temperature within the range studied, i.e. 1250–1600° C. There is close agreement among the data of different origins for gas ratios p_{CO_2}/p_{CO} greater than 1·0. At lower oxygen potentials, however, the authors' results deviate somewhat from those of Michal and Schuhmann.[11] To ascertain that this deviation was not due to the temperature differences of 200–300° C in these two sets of data, three additional experiments were done: two at 1450° C and one at 1600° C (D5, D6, and D7 in Table I). As seen from Fig. 4, these results

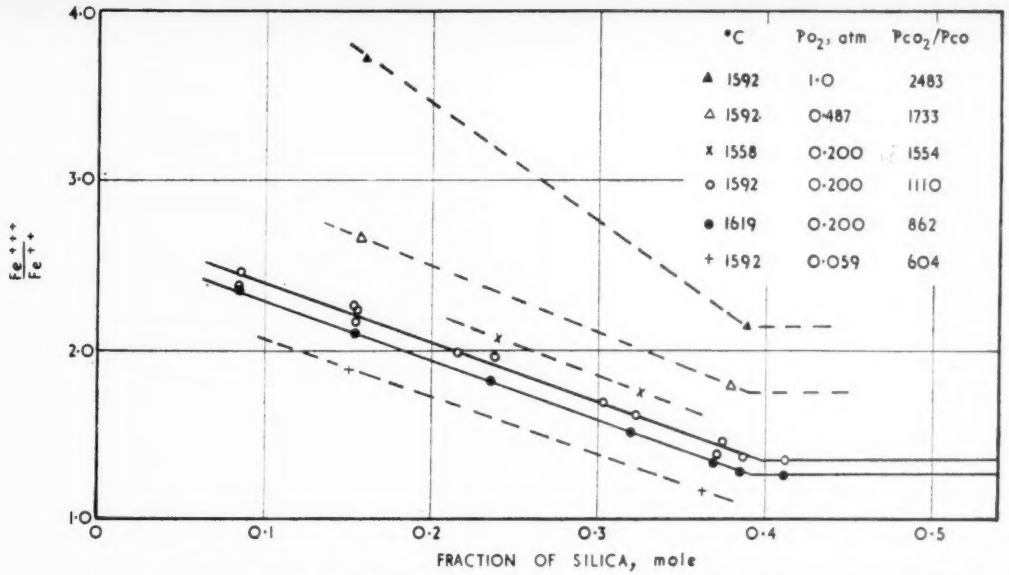


Fig. 3—Variation of the Fe^{+++} Fe^{++} ratio with gas and slag composition in the FeO–Fe_2O_3–SiO_2 system from the data of White[6]

are concordant with those for 1550° C. Michal and Schuhmann do not give the details of their method of analysis; in the present work several methods were tried, and since the one described earlier in the paper gave reproducible results, a greater weight is given to the authors' results in drawing the curve at the low p_{CO_2}/p_{CO} ratios.

The dotted line drawn in Fig. 4 with a slope of 2·0 has a certain theoretical significance and will be dealt with more fully later in the discussion. The lower part of the curve drawn in this diagram by a full line terminates at the point where at 1550° C the silica-saturated melt is in equilibrium with liquid iron. In order to obtain this limiting value two experiments, D3 and D4, were carried out. On examination of the fracture of the samples D3 and D4 under a low-power microscope, it was observed that whilst the sample D3 was free of metallic iron, in silicate D4 a few globules of iron were present. This indicates that FeO–Fe_2O_3–SiO_2 melt saturated with cristobalite is in equilibrium with liquid iron at 1550° C in an atmosphere where p_{CO_2}/p_{CO} is between 0·089 and 0·083. The amount of metallic iron in sample D4 was very small compared with the bulk of the silicate and, therefore, any error involved in the analysis of this sample for ferrous oxide was considered negligible.

As illustrated in Fig. 5, the solubility of cristobalite in molten oxides of iron is influenced by the partial

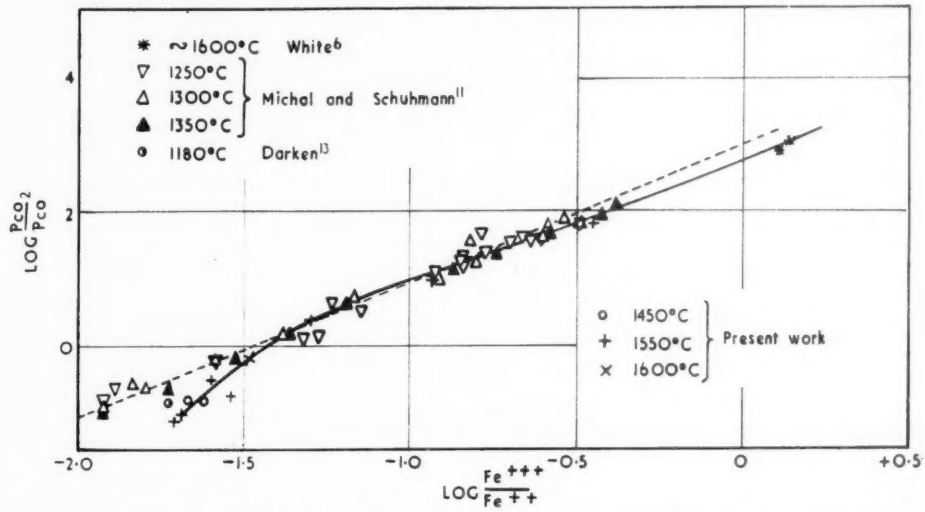


Fig. 4—Variation of Fe^{+++} Fe^{++} with p_{CO_2} p_{CO} in the silica-saturated FeO–Fe_2O_3–SiO_2 system

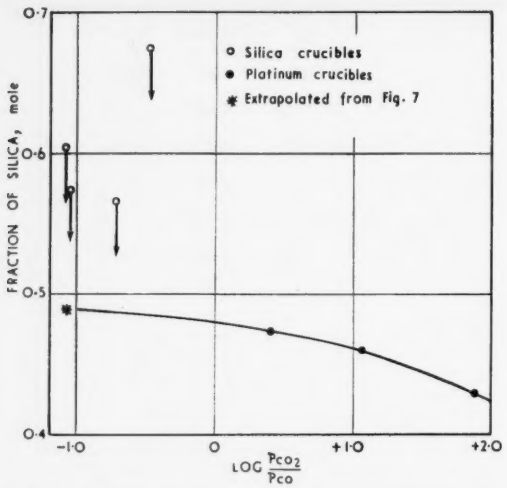


Fig. 5—Effect of oxygen partial pressure on the solubility of cristobalite in $FeO–Fe_2O_3$ melts at 1550° C

pressure of oxygen in equilibrium with the melt. The values for the gas compositions given by $p_{CO_2}/p_{CO} = 75{\cdot}0$, 11·4, and 2·5 are obtained from the intersection points in Fig. 2. The results from melts in silica crucibles are rather high, and this is thought to arise from the contamination of the melts with silica in excess of saturation as a result of spalling of the crucible walls on heating. It should, however, be pointed out that the Fe^{+++}/Fe^{++} ratios obtained from the analysis of the samples in series D should be unaffected by the presence of excess silica.

$FeO–Fe_2O_3–P_2O_5$ Ternary and $FeO–Fe_2O_3–SiO_2–P_2O_5$ Quaternary Systems

Similar experiments were carried out with melts using phosphorus pentoxide instead of, and in addition to, silica. The results are plotted in Fig. 6, together with curves from Fig. 2 for comparison. Since the concentration of phosphorus pentoxide varies within a wide range, the points in Fig. 6 are not expected to fall on a single smooth curve for a given oxygen potential. Later it will be attempted to show the effect of phosphorus pentoxide on the Fe^{+++}/Fe^{++} ratio relative to that of silica in the ternary and quaternary melts.

Comparison of the melts E1, F1, G1, and G2 with the curves in Fig. 6 indicates that the lowering effect of phosphorus pentoxide on the Fe^{+++}/Fe^{++} ratio is greater than that of silica at the same molecular concentration. For example, in melt E1, $N_{P_2O_5} = 0{\cdot}248$ and $Fe^{+++}/Fe^{++} = 0{\cdot}161$, whilst for the same $p_{CO_2}/p_{CO} = 75{\cdot}0$ and $N_{SiO_2} = 0{\cdot}248$, the ratio $Fe^{+++}/Fe^{++} = 0{\cdot}565$, in the iron-oxides–silica melts.

DISCUSSION

From the curves given by Michal and Schuhmann[11] for 1250°, 1300°, and 1350° C, the solubility of silica in $FeO–Fe_2O_3$ melts has been plotted against temperature in Fig. 7 for various p_{CO_2}/p_{CO} ratios. The extension of the lines to 1550° C gives data which are compatible with the present results (see Fig. 2). The top line is for the melts in equilibrium with iron (γ, δ, or liquid). The results of Bowen and Schairer[14] at 1260° and 1515° C agree well with those of recent investigators.[10, 11, 15] The extrapolation of the line to 1550° C gives $N_{SiO_2} = 0{\cdot}489$ as the solubility of cristobalite in molten iron oxides in equilibrium with liquid iron. This value has been used in Fig. 5 to extrapolate the curve to lower levels of oxygen partial pressures.

In Fig. 8, log p_{CO_2}/p_{CO} is plotted against the reciprocal of the absolute temperature for the $FeO–Fe_2O_3$ binary system from the results of Darken and Gurry,[8] and for the $FeO–Fe_2O_3–SiO_2$ ternary system (saturated with silica) from the results of Michal and Schuhmann,[11] Darken,[13] Gokcen and Chipman,[16] and the authors. In both systems the melts are in equilibrium with iron (γ, δ, or liquid). Although the data for the binary system are from 1400° to 1600° C, by correcting for the $\gamma \rightarrow \delta$ transformation,[17] the curve may be extended to the γ-iron region where the iron oxide melt is in a metastable state.

From the data in Fig. 8 it is possible to calculate the activity of ferrous oxide in silica-saturated melts by assigning unit activity to molten wüstite in equilibrium with iron at any temperature. (Slight variation in the composition of wüstite with temperature has a negligible effect on the computations based on this standard state). The first four results given in

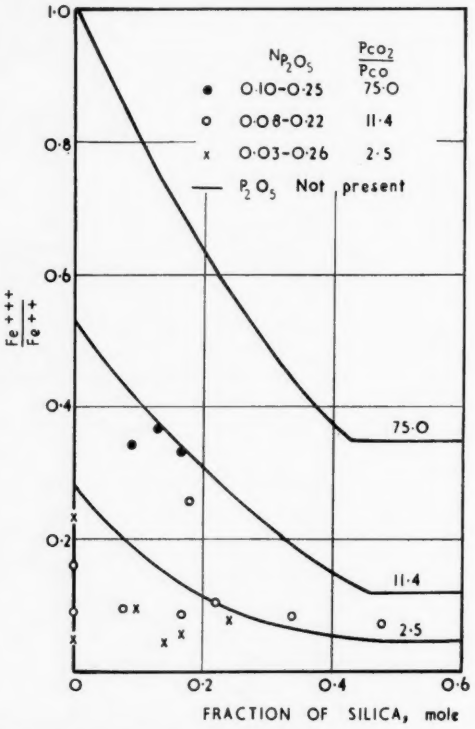


Fig. 6—Effect of silica on the Fe^{+++}/Fe^{++} ratio at 1550° C in the $FeO–Fe_2O_3–SiO_2–P_2O_5$ system. Curves for comparison are for melts free of phosphorus pentoxide

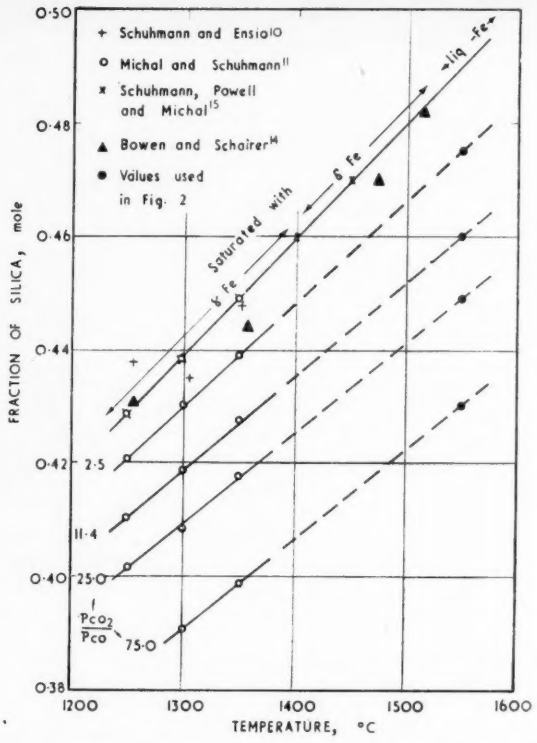
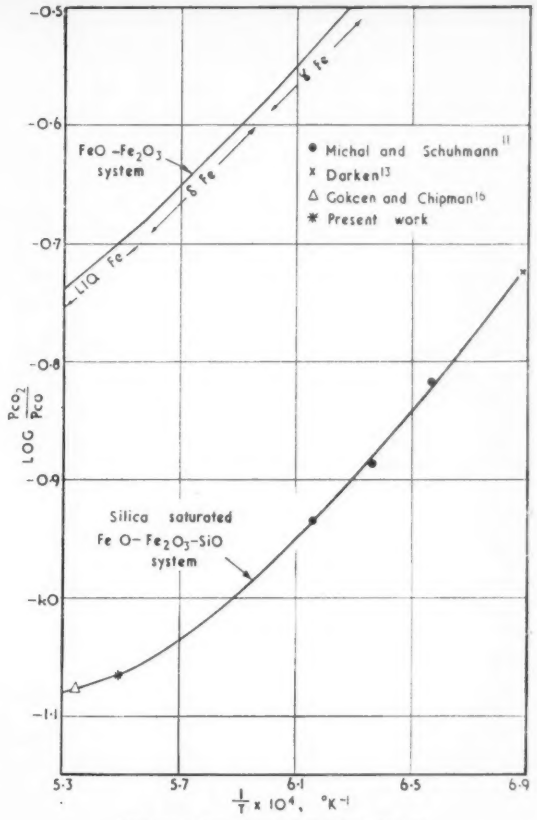


Fig. 7—Effect of temperature and oxygen partial pressure on the solubility of silica in the molten FeO–Fe_2O_3 system



Note: In above diagram SiO should be SiO_2

Fig. 8—Variation of p_{CO_2}/p_{CO} with temperature for melts in equilibrium with solid silica and iron (γ, δ, or liq.)

Table II are taken from the data calculated by Michal and Schuhmann.[11] All the slag compositions, however, are computed from the relationships in Figs. 4 and 7. The value of $p_{CO_2}/p_{CO} = 0{\cdot}086$ for 1550° C is the mean of the two measurements (see melts D3 and D4 in Table I).

According to Gokcen and Chipman,[16] the solubility of oxygen in iron–silicon melts in equilibrium with cristobalite-saturated iron oxide is 0·088% at a gas composition $p_{H_2O}/p_{H_2} = 0{\cdot}35$.

Both of these values can be converted to the equivalent of p_{CO_2}/p_{CO} ratio by using available thermodynamic data[8, 18] to give $p_{CO_2}/p_{CO} = 0{\cdot}084$ which gives $a_{FeO} = 0{\cdot}449$. Gokcen and Chipman, however, calculated the ferrous oxide activity as 0·391 from the ratio 0·088/0·225, where 0·225% is the solubility of oxygen in liquid iron in equilibrium with wüstite[5] at 1600° C.

The variation of the Fe^{+++}/Fe^{++} ratio in the ternary melts FeO–Fe_2O_3–SiO_2 with the gas ratio p_{CO_2}/p_{CO} and the silicate composition is shown in Fig. 9. The closed circle points are read off the curves in Figs. 2 and 4 and the open circles are interpolated for 1550° C from the results of Darken and Gurry.[8] Although the data in Fig. 9 are for 1550° C, they could also be used quite safely for other temperatures for the following reasons. It is clear from Fig. 4 that, at silica saturation, the value of the Fe^{+++}/Fe^{++} ratio is not affected by the temperature within the

Table II

ACTIVITY OF FERROUS OXIDE IN FeO–Fe_2O_3–SiO_2 MELTS IN EQUILIBRIUM WITH SILICA AND IRON (γ OR LIQUID)

°C	N_{FeO}	$N_{Fe_2O_3}$	N_{SiO_2}	$\frac{Fe^{+++}}{Fe^{++}}$	$\frac{p_{CO_2}}{p_{CO}}$	a_{FeO}	γ_{FeO}
1180	0·578	0·007	0·415	0·0234	0·189	0·414	0·716
1250	0·564	0·007	0·429	0·0224	0·152	0·406	0·722
1300	0·555	0·006	0·439	0·0219	0·132	0·399	0·719
1350	0·545	0·006	0·449	0·0211	0·116	0·393	0·723
1550	0·506	0·005	0·489	0·0201	0·086	0·431	0·851
1600	0·496	0·005	0·499	0·020	0·084	0·449	0·905

range studied, i.e. 1250–1600° C. It was also shown by Darken and Gurry[8] that, in the iron–oxygen binary system, temperature has a negligible influence on the Fe^{+++}/Fe^{++} ratio. Similarly, the work of Larson and Chipman[12] indicated that the temperature effect was within the limits of the experimental error. The temperature insensitiveness of the relationship in Fig. 9 is a fortuitous result of the following two factors operating simultaneously: first, for a given p_{CO_2}/p_{CO} ratio, increase in temperature increases the equilibrium partial pressure of oxygen, and secondly, for a given partial pressure of oxygen and silicate composition, the Fe^{+++}/Fe^{++} ratio decreases with increase in temperature.

Although the curves in Fig. 9 on the extreme side of the system extend down to the liquid iron region, there are no data for melts of intermediate compositions below $p_{CO_2}/p_{CO} = 2{\cdot}5$. This extrapolated part of the curve shown by dotted lines should not be in excessive error. Experiments done within this region were unsuccessful because of the attack of iron oxide on platinum crucibles.

The oxidation of ferrous iron to ferric iron, both in solution in molten slag, may be represented by the following expressions:

$$2Fe^{++} + CO_2 = 2Fe^{+++} + O'' + CO \quad \ldots\ldots(1)$$

or

$$2Fe^{++} + \tfrac{1}{2}O_2 = 2Fe^{+++} + O'' \quad \ldots\ldots(2)$$

It follows from the above expressions that for a given temperature and oxygen partial pressure, a decrease in the oxide ion (O'') activity of the melt increases the activity ratio $a_{Fe^{+++}}/a_{Fe^{++}}$. Since silicon ions form complex anions with oxygen, the oxide ion activity of the slag decreases with increase in silica content and this brings about a rise in the activity ratio $a_{Fe^{+++}}/a_{Fe^{++}}$. The experimental evidence, on the other hand (Figs. 2 and 9) indicates that for a given temperature and p_{CO_2}/p_{CO}, the concentration ratio Fe^{+++}/Fe^{++} decreases appreciably with increase in silica concentration. It follows, therefore, that as the silicon–oxygen network becomes more complex the activity coefficient ratio $\gamma_{Fe^{+++}}/\gamma_{Fe^{++}}$ increases at a rate much greater than that of the activity ratio $a_{Fe^{+++}}/a_{Fe^{++}}$.

The experimental data so far discussed indicate that at silica saturation there is only a little change in the silica content of the melt, with changing partial pressure of oxygen; for example, at 1550° C at $p_{CO_2}/p_{CO} = 75{\cdot}0$, $N_{FeO} = 0{\cdot}485$, $N_{Fe_2O_3} = 0{\cdot}085$ and $N_{SiO_2} = 0{\cdot}430$, and at a gas ratio $p_{CO_2}/p_{CO} = 0{\cdot}086$, $N_{FeO} = 0{\cdot}506$, $N_{Fe_2O_3} = 0{\cdot}005$ and $N_{SiO_2} = 0{\cdot}489$. At silica saturation little change is therefore expected in the degree of interaction of cations and complex anions. Consider now the following expression derived from reaction (2):

$$\log \frac{p_{CO_2}}{p_{CO}} = 2 \log \frac{Fe^{+++}}{Fe^{++}} + 2 \log \frac{\gamma Fe^{+++}}{\gamma Fe^{++}} + \log a^{O''} - \log K \quad \ldots\ldots(3)$$

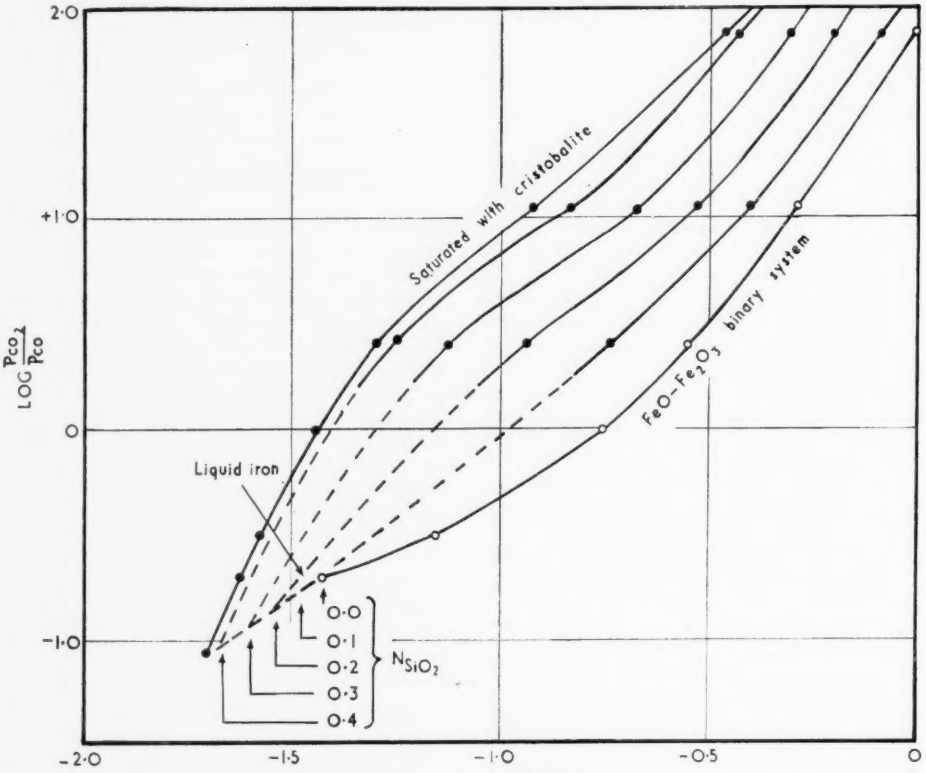


Fig. 9—Variation of Fe^{+++}/Fe^{++} with silicate and gas composition in the $FeO–Fe_2O_3–SiO_2$ system at 1550° C

where K is the equilibrium constant of reaction (1) and $a_{O''}$ is the oxide ion activity of the silicate. If the term [2 log $(\gamma_{Fe^{+++}}/\gamma_{Fe^{++}})$ + log $a_{O''}$] remains constant at silica saturation, then the plot of log p_{CO_2}/p_{CO} against log Fe^{+++}/Fe^{++} should give a straight line with a slope of two; such a line (dotted) drawn in Fig. 4 supports the above argument. With respect to this part of the discussion reference should also be made to the work of Richardson and Billington[19] who have expressed similar thoughts along these lines. According to the results in Fig. 4, however, there is some deviation from linearity at low and high partial pressures of oxygen, where there is a slight decrease in the term [2 log $(\gamma_{Fe^{+++}}/\gamma_{Fe^{++}})$ + log $a_{O''}$].

The shapes of the curves in Fig. 9 indicate that for any given silica concentrations, even at zero silica percentage, the variation in log Fe^{+++}/Fe^{++} with log p_{CO_2}/p_{CO} is not in accordance with expression (3) for the following reasons: for a given silicon–oxygen anion complex (*a*) oxide ion activity changes with Fe^{+++}/Fe^{++}, (*b*) $\gamma_{Fe^{+++}}/\gamma_{Fe^{++}}$ changes with Fe^{+++}/Fe^{++}, and (*c*) all the ferric iron is not in the Fe^{+++} form, but some interacts with oxygen to give network-forming ferrite anions.

Much work has been done on the light-absorption properties of glasses containing iron, especially by Weyl[20, 21] and Stevels.[22] It is now a well established view that iron in glasses occurs as (*a*) ferrous cations, Fe^{++}, as network-modifier; (*b*) ferric cations, Fe^{+++}, as network-modifier; and (*c*) ferrite anion complex as network-former. These three entities always co-exist and their proportions depend on the oxygen potential and the composition of the system. The ferrous cations in glasses possess a characteristic infra-red absorption band extending into the visible region, causing the glass to be bluish in colour under reducing conditions. The ferric cations, however, absorb the light in the ultra-violet range extending towards the visible region causing a faint pink colour. As the concentrations of the network-forming ions, e.g. P^{5+}, Si^{4+}, B^{3+}, decrease, more of the trivalent iron associates itself with the available oxide ions to form ferrite anion complexes which increase the absorption power of the base glass causing yellow to brown colours. In addition, there is the interaction to be considered between the ferrous cations and oxyacid radicals. As discussed by Weyl,[21] the interaction between ferrous cations and ferrite anions increases as the proportion of strong network-forming ions decreases, shifting the absorption band to the longer wavelength regions.

It appears from the foregoing discussions that total ferric iron concentration can be used in the Law of Mass Action expression only for systems saturated with silica where the ferrite anion formation is negligible. For a given oxygen partial pressure, the lowering of silica concentrations, and consequent increase in the Fe^{+++}/Fe^{++} ratio (Fig. 9) is accompanied by an increase in the proportion of the ferrite anions, and a reaction of the following type may occur.

$$2Fe^{+++} + 4O'' = Fe_2O''_4 \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The formula, $Fe_2O''_4$, used in this expression is a mere example; in slags containing iron, the iron/oxygen ratio and the electronegative charge of the ferrite anion will vary with the composition and the oxygen potential of the system.

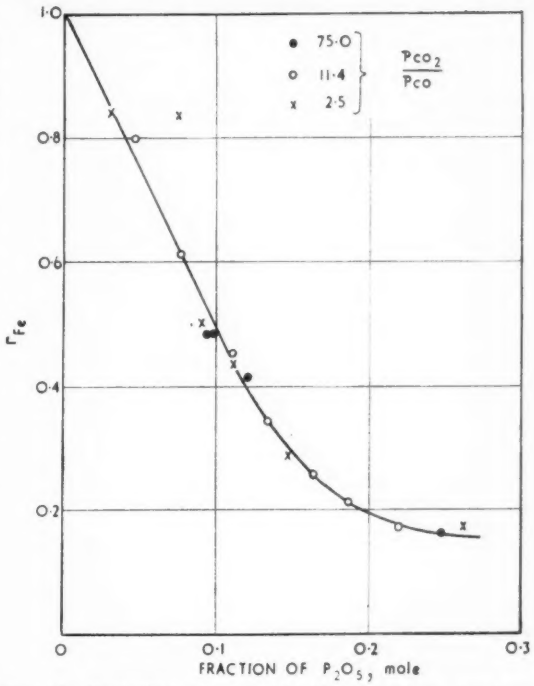


Fig. 10—Variation of r_{Fe} with $N_{P_2O_5}$ at three p_{CO_2}/p_{CO} ratios and various silica concentrations at 1550° C in the FeO–Fe_2O_3–SiO_2–P_2O_5 system

In considering the thermodynamics of any solution it is not necessary to know the true constitution of the system, and therefore it is quite sufficient to state that when the total trivalent iron is represented by Fe^{+++}, any change in composition leading to ferrite anion formation will lower the activity, and probably the activity coefficient of Fe^{+++}. As the stronger network-formers, e.g. P^{5+}, Si^{4+}, are replaced by the ferric ions, the interaction between the cations, e.g. Fe^{++}, Ca^{++}, Mg^{++}, and the anion complexes will be reduced because of the weaker bonding between these cations and the ferrite anions; this state of affairs will result in an increase in the activity of ferrous cations.

Phosphorus pentoxide, like silica, lowers the Fe^{+++}/Fe^{++} ratio (Fig. 6). This effect of phosphorus pentoxide, relative to that of silica, may be obtained from the following ratio:

$$r_{Fe} = \frac{(Fe^{+++}/Fe^{++})_{Si,\,P}}{(Fe^{+++}/Fe^{++})_{Si}}$$

(for a given N_{SiO_2} and p_{CO_2}/p_{CO}).....(5)

where the subscripts Si, P indicate the FeO–Fe_2O_3–SiO_2–P_2O_5 quaternary system and Si indicates the FeO–Fe_2O_3–SiO_2 ternary system, i.e. r_{Fe} is the ratio of $(Fe^{+++}/Fe^{++})_{Si,\,P}$ in the quaternary system to that in the ternary system for a given silica concentration and oxygen partial pressure. This factor r_{Fe}, obtained from the values of Fe^{+++}/Fe^{++} ratios in

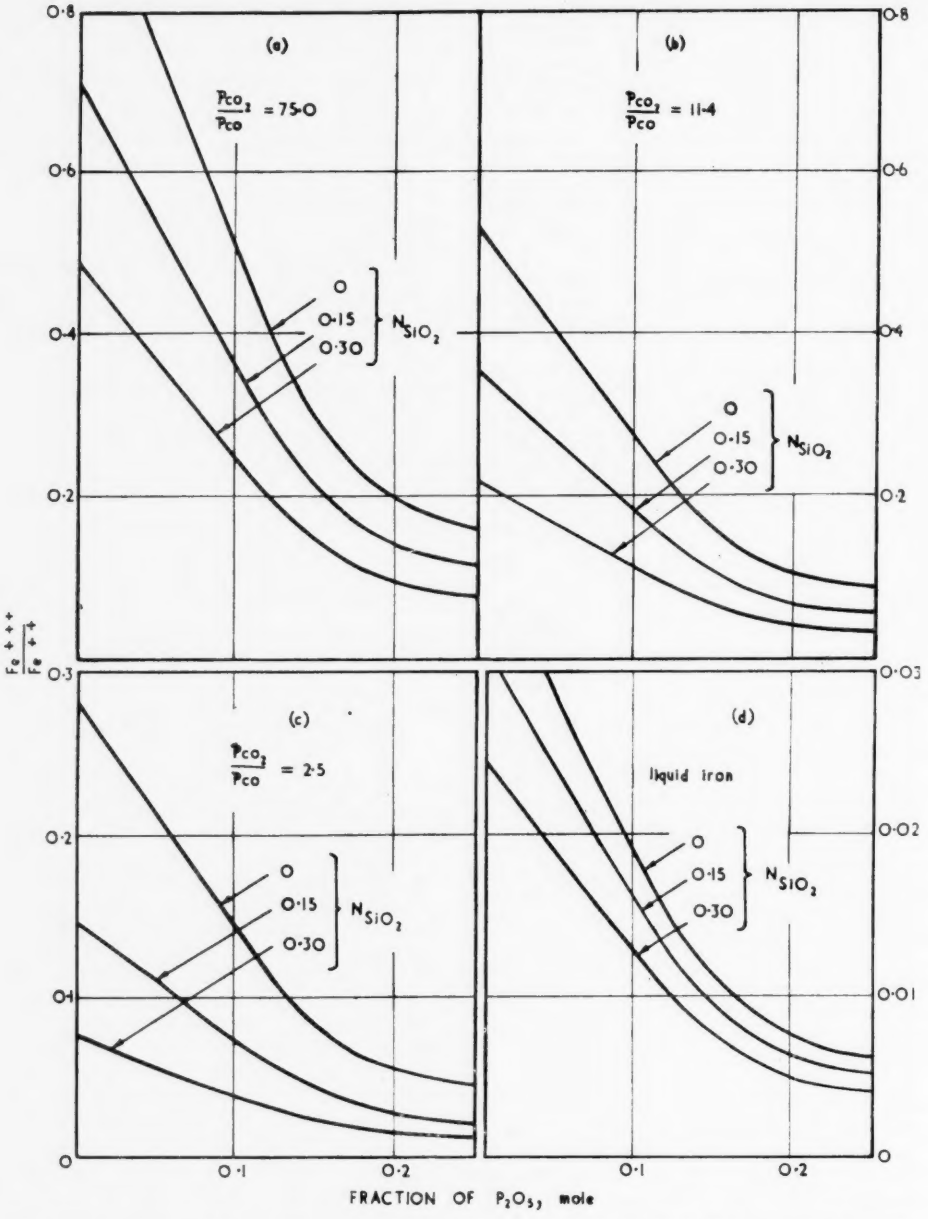


Fig. 11—Variation of Fe^{+++}/Fe^{++} with composition in FeO–Fe_2O_3–SiO_2–P_2O_5 melts at 1550° C

series E, F, and G of Table I and the curves in Fig. 2, is plotted against the mole fraction of phosphorus pentoxide in Fig. 10. There are two characteristic features of this relationship: firstly, it is independent of the oxygen partial pressure, and secondly, it is not affected by the silica content of the slag within the range studied, i.e. zero to about 40% SiO_2.

It is important to note that phosphorus pentoxide lowers the Fe^{+++}/Fe^{++} ratio to a greater extent than does silica at the same concentration; at higher concentrations, phosphorus pentoxide becomes less effective. Although the equivalence of $N_{P_2O_5}$ relative to N_{SiO_2} is a complex function, the relationship in Fig. 10 at low values of $N_{P_2O_5}$ may be assumed linear and represented by the following expression:

$$r_{Fe} = -5N_{P_2O_5} + 1$$
when $N_{P_2O_5} < 0{\cdot}1$, i.e. less than 20% P_2O_5...(6)

The behaviour of phosphorus pentoxide relative to silica in these melts is very analogous to that in phosphate glasses.[20] The phosphorus ions (P^{5+}) are stronger network-formers than silicon ions (Si^{4+})

which, in turn, are much stronger than ferric ions (Fe^{3+}); consequently, when some of the silicon ions are replaced by the phosphorus ions, there will be fewer oxygen ions available for the ferric ions to form ferrite anions. In other words, the activity of Fe^{+++} will increase when silica is replaced by phosphorus pentoxide, even if the sum of $N_{SiO_2} + N_{P_2O_5}$ remains the same or is reduced slightly.

Since the relationship in Fig. 10 is independent of the silica concentration and the partial pressure of oxygen, this curve together with those in Fig. 2 can be used to evaluate the variation of Fe^{+++}/Fe^{++} with phosphorus pentoxide for any silica content and p_{CO_2}/p_{CO} ratio. The computed results have been plotted in Figs. 11*a*, *b*, *c*, and *d* for 0, 0·15, and 0·30 mole fractions of silica and for p_{CO_2}/p_{CO} ratios of 75·0, 11·4, and 2·5, and for melts in equilibrium with liquid iron. In the latter case (Fig. 11*d*) the curves for N_{SiO_2} 0·15 and 0·30 are based on the assumed line in Fig. 9 joining the two points for silica-free and silica-saturated melts in equilibrium with liquid iron. Errors arising from this assumption will be no more than the errors involved in the experiments at very low oxygen partial pressures.

Although the curves in Fig. 11 are for melts at 1550° C, for the reasons discussed previously, these data can be applied with confidence to other temperatures.

CONCLUSION

In the ternary systems $FeO–Fe_2O_3–SiO_2$, for a given partial pressure of oxygen, the Fe^{+++}/Fe^{++} ratio decreases as the silica content of the melt increases, and for a given silica content, the Fe^{+++}/Fe^{++} ratio decreases with decrease in oxygen partial pressure. In both cases this change of state leads to (*a*) dissociation of ferrite anion complexes, (*b*) the formation of more complex silicon–oxygen network, and (*c*) the occupation of sites in the interstices of the silicon–oxygen network by ferrous cations originally interacting with ferrite anions. This state of affairs leads to an increase in the activity coefficient ratio $\gamma_{Fe^{+++}}/\gamma_{Fe^{++}}$.

Since phosphorus ions are stronger network-formers than silicon ions, the replacement of silica by phosphorus pentoxide, for a given oxygen partial pressure, decreases the concentration ratio Fe^{+++}/Fe^{++} and increases the activity coefficient ratio $\gamma_{Fe^{+++}}/\gamma_{Fe^{++}}$, even though the sum of the acidic oxides, i.e. $N_{SiO_2} + N_{P_2O_5}$, may remain the same or be reduced slightly.

References

1. C. H. Herty, J. M. Gaines, B. M. Larsen, W. A. Simkins, R. L. Geruso, and S. P. Watkins: *Mining and Metallurgical Investigations*, Bulletin 34, 1927.
2. F. Körber and W. Oelsen: *Mitt. Kaiser-Wilhelm Inst. Eisenforsch.*, 1932, vol. 14, pp. 181–204.
3. J. Chipman and K. L. Fetters: *Trans. Amer. Soc. Metals*, 1941, vol. 29, pp. 953–966.
4. K. L. Fetters and J. Chipman: *Trans. Amer. Inst. Min. Met. Eng.*, 1941, vol. 145, pp. 95–107.
5. C. R. Taylor and J. Chipman: *Ibid.*, 1943, vol. 154, pp. 228–247.
6. J. White: *Carnegie Scholarship Memoirs, Iron Steel Inst.*, 1938, vol. 27, pp. 1–75.
7. L. S. Darken and R. W. Gurry: *J. Amer. Chem. Soc.*, 1945, vol. 67, pp. 1398–1412.
8. L. S. Darken and R. W. Gurry: *Ibid.*, 1946, vol. 68, pp. 798–816.
9. R. W. Gurry and L. S. Darken: *Ibid.*, 1950, vol. 72, pp. 3906–3910.
10. R. Schuhmann and P. J. Ensio: *Trans. Amer. Inst. Min. Met. Eng.*, 1951, vol. 191, pp. 401–411.
11. E. J. Michal and R. Schuhmann: *Ibid.*, 1952, vol. 194, pp. 723–728.
12. H. Larson and J. Chipman: *Ibid.*, 1953, vol. 197, pp. 1089–1096.
13. L. S. Darken: *J. Amer. Chem. Soc.*, 1948, vol. 70, pp. 2046–2053.
14. N. L. Bowen and J. F. Schairer: *Amer. J. Sci.*, 1932, vol. 24, pp. 177–213.
15. R. Schuhmann, R. G. Powell, and E. J. Michal: *Trans. Amer. Inst. Min. Met. Eng.*, 1953, vol. 197, pp. 1097–1104.
16. N. A. Gokcen and J. Chipman: *Ibid.*, 1952, vol. 194, pp. 171–181.
17. L. S. Darken and R. P. Smith: *Indust. Eng. Chem.*, 1951, vol. 43, pp. 1815–1820.
18. "Selected Values of Chemical Thermodynamic Properties," series III, 1947 *et seq.*, Department of Commerce, National Bureau of Standards, Washington, D.C., U.S.A.
19. F. D. Richardson and J. C. Billington: *Trans. Inst. Min. Met.*, 1955–56, vol. 65, pp. 273–297.
20. W. A. Weyl, "Coloured Glasses," 1951, Society of Glass Technology, Sheffield.
21. W. A. Weyl, "Light Absorption as a Result of an Interaction of Two States of Valency of the Same Element: Iron": 1950, January, Penn. State-Cont. No. N6 our 269, Task Order 11, NR 081–060.
22. J. M. Stevels: *Verres et Réfract.*, 1949, vol. 3, pp. 359–368.

DISCUSSION ON PAPERS

Discussion at Meetings · Written Contributions

Autumn General Meeting, 1956

THE AUTUMN GENERAL MEETING of THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 21st and 22nd November, 1956, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, Dr. H. H. Burton, was in the Chair. During the latter part of the meeting, in the unavoidable absence of the President, the Chair was taken by Mr. J. Mitchell (*Vice-President*) and by Mr. K. Headlam-Morley (*Secretary*).

DISCUSSION ON CREEP-RESISTING STEELS

This discussion was based on the paper by M. G. Gemmill, H. Hughes, J. D. Murray, F. B. Pickering, and K. W. Andrews, entitled **"Study of 7% and 8% Chromium Creep-resisting Steels for Use in Steam Power Plant,"** which appeared in the October, 1956, issue of the *Journal* (vol. 184, pp. 122–144).

Mr. **M. G. Gemmill** (Central Electricity Authority) presented the paper.

Mr. **H. C. Child** (Wm. Jessop and Sons, Ltd.): The approach in this work is similar to that in many other previous investigations, in that compositional changes have been made to the steel, and then a standard creep test carried out to assess the effect. In interpreting these data it is important to stress something which Mr. Gemmill has already hinted at, but not gone into very deeply, that these compositional changes may be expected to affect two or three metallurgical factors of the material: first, solid-solution hardening; second, precipitation hardening; and third, the strain-hardening characteristics of the alloy. The paper says little about the strain-hardening aspect, but I would like to consider the other two factors and how they might be expected to affect not only the rupture strength which has been the main basis of the paper, but also creep strength.

The 8% Cr–Mo–Ti alloy, as has been pointed out, is completely ferritic at all temperatures, and hence metallurgically it resembles austenitic alloys rather than hardenable steels; in other words there is no transformation hardening to complicate the issue. From Table IV of the paper we find that, using optimum ageing conditions, we can increase the rupture strength by a factor of about 5% in terms of stress. This is assuming that the slope of the stress/rupture-time curves is constant with different ageing treatments. It will also be seen from Table IV that the effect of precipitating the iron–titanium phase can cause a drop in the rupture strength of 25% on the same basis. This leads one to the assumption that to obtain optimum rupture strength for this alloy the important effect is solid-solution hardening, as even with an optimum age-hardening treatment carried out prior to the test we are getting relatively insignificant improvement in rupture strength, whereas if the matrix is impoverished in titanium by precipitating the iron–titanium phase, the rupture strength is significantly diminished.

It is important to appreciate, however, that prior ageing, although it may not have a beneficial effect on the rupture strength for this alloy, will probably improve the creep strength based on a low strain criterion of, say, 0·1%. Referring to Fig. 24, I think Mr. Gemmill and his colleagues will agree that if they had carried out prior ageing at 550° C the creep strength of the 8% Cr–Mo–Ti steel would have been very significantly improved in the temperature range 600–650° C and we would have had a line for the 8% Cr–Mo–Ti steel roughly parallel to the lines for the Cr–Mo and the austenitic material. In other words, the importance of age-hardening an alloy prior to service diminishes as the criterion of failure changes from low strain criteria through high strain criteria to rupture. Similarly, the importance of this effect diminishes as the service life increases.

In considering the two factors, solid-solution hardening and precipitation hardening, as metallurgical variables affecting creep strength, it is unfortunate that there can be two interpretations of the phenomenon. If we consider that the most important effect is solid-solution hardening, we will choose the chemical composition to give the maximum lattice strain commensurate with a slow decomposition of the supersaturated solid solution which will exist in the heat-treated state. If the supersaturated solution decomposes, the effectiveness of the solid-solution hardening is lost.

If one considers that the precipitation hardening effect

is the more important, it is still necessary to choose a composition having a supersaturated solid solution in the heat-treated state which will precipitate slowly under the action of stress and temperature. If the supersaturated solution is unstable at the test temperature, the resulting precipitation will be fast, and non-coherent precipitates will be readily produced which will have a minimum strengthening effect.

This goes to show that it is exceedingly difficult to disentangle the two effects, solid-solution hardening and precipitation hardening.

There are one or two minor points in the paper which are not clear to me. Figure 1 seems to refer to a series of steels of different compositions. If this is the case, then one would anticipate that the varying Mo and Al additions will not only suppress the formation of austenite, but will also increase solid-solution hardening. If this is true, then surely it is wrong to infer that one wants to suppress formation of austenite to promote creep strength. There is a danger that Fig. 1 may be taken as a general statement that the suppression of austenite is desirable, and not as a particular one that the Mo and Al additions which suppress austenite also strengthen alloys by solid-solution hardening. It has been our experience that alloys can be developed containing any percentage of δ-ferrite from 0 to 100% having the same creep strength and it is this which leads me to draw attention to this figure.

Another minor point is the effect of chromium on creep strength. Here again, there is a suggestion that higher chromium alloys, fully ferritic, cannot be developed to the same creep strength. This is contrary to our own experience where non-hardenable ferritic steels of the type described by the authors have been developed containing 12–16% Cr and strength levels have been achieved of the same order as those described here. As the highest chromium content steel examined by the authors has a very satisfactory creep strength, and as there is a pronounced minimum at intermediate chromium levels, this suggests that the authors' experimental evidence does not really point to higher chromium contents as being undesirable.

In the paper the authors have compared the 8% Cr–Mo–Ti steel with other materials used for steam plant, and it is important to remember that there are gas-turbine materials which have very similar creep strength to this steel, e.g. 12% Cr complex steels of the H 46 and Rex 448 type. These gas-turbine materials are not suitable for steam plant because of difficulties in welding, and therefore the practical application of the authors' alloy must depend largely on the question of its weldability. Mr. Gemmill has mentioned welding tests, but it is a pity that space has stopped the authors giving more details of these tests in view of their importance.

Assuming that the material can be welded, the creep strength appears to be quite adequate, and we are left to consider the other mechanical properties. The impact strength is unfortunately low, and while the authors stress that the impact strength at temperature is quite adequate, engineers generally insist on adequate cold impact strength to facilitate construction, fitting etc., and do not relish the prospects of an Izod value of 2 or 3 ft-lb.

Perhaps a more serious objection is the low room-temperature ductility. On bar material this is as low as 6% in the solution-treated condition, and after ageing for 100 h at 550° C is reduced to 2% (*see* Table IX). Hot welding of superheater tubes is quite common, and it is therefore likely that we would have cases of superheater tubes ageing during the welding process in this rather critical temperature range, and we would have cases of very low room-temperature ductility. Also some parts of the plant, if supplied in the normalized condition, would probably embrittle in service if the temperature of the part lay in the critical range 500–550° C.

Dr. **N. P. Allen** (National Physical Laboratory): There are at least three compositions of steel which are sufficiently oxidation- and creep-resistant; this paper describes the first of them. The question now is not whether it is possible to have steels of this kind but which of the steels available is the most practical.

The steels that are available have interesting differences, and it may be useful to point out one or two.

Of these steels, the one now under consideration is completely α, another is an $\alpha + \gamma$ mixture, and another is completely γ. They all have about the same standard of creep resistance. The γ steel is harder, the steel under discussion is soft, and the $\alpha + \gamma$ is intermediate. That is a point of great advantage, because sometimes one needs hard steels and sometimes one needs soft steels. It is interesting to note that in compositions of this kind one can have a range of properties.

Our experience at the N.P.L. confirms the authors' experience to the extent that it seems to be easier to get the required standard of creep resistance in an α steel. We find that precipitation hardening is a help in obtaining the required properties, and it seems that the necessary small finely-dispersed stable precipitates are more easily formed in the α constituent than in the γ. In confirmation of that idea we find that the γ steels that have been produced are more complicated and the α more simple, indicating that you must be a little more clever in your metallurgical work to get the required standard of creep resistance with the γ.

The authors are to be congratulated on the work they have done on the precipitation-hardening effect, and in distinguishing the effects produced by titanium alone and by precipitation of the complex carbide $M_{23}C_6$. It illustrates very clearly an important point, that it is not sufficient to produce a precipitation hardening effect; the precipitate must be stable at the temperature at which the material is to be used.

We find in fact that the type of precipitant can be varied considerably, and that although the $M_{23}C_6$ is a comparatively stable precipitant, there are other compounds which are more stable than the $M_{23}C_6$, and that one can get advantages by using such compounds.

It is hardly worth while going into a controversy as to whether precipitation hardening or solid-solution hardening is the important thing in producing creep resistance, because there is very clear evidence that good creep-resisting alloys need to take advantage of both types of hardening.

Turning to the creep properties obtained, I think that the most important table that has been produced is Table IX, in which it is shown that at a temperature of about 625° C, one can get a creep-rupture life greater than 10,000 h with a stress of 6 tons/in². What would happen at 100,000 h is not entirely certain, but I believe that one could have materials with satisfactory lives of 10–20 years under stresses of the order of 2 or 3 tons/in² at that temperature. That strength is sufficient to give these steels a real chance of application.

I would, however, disagree with the authors in their remarks about the desirability of the precipitation occurring during the service rather than before. Figures 25 and 26 show the danger. If one relies on precipitation during the course of operation, then one is very likely to get an unduly large amount of deformation in the early stages of use. In the case of a superheater tube this does not matter much, but in materials which are used under relaxation conditions, e.g. bolts and pipe flanges, then that early amount of deformation would become quite important, and it would be desirable to make sure

that from the beginning the material had a high standard of creep resistance.

Finally, this subject must be pursued until we find the practical composition which has the necessary properties. I feel certain that it is a material of the general type that has been studied and it is a matter of choosing the best one and the best way of producing the properties that are needed. This is important, in spite of the fact that the present tendency is to say that atomic power plant is governing the situation and requires materials that operate at temperatures much lower than 600° C. We are apt to forget that it will not be very long before atomic power is regarded as quite normal and people will be pointing out how very ridiculous it is to employ expensive materials like uranium and plutonium, and only make use of a fraction of the power they are capable of producing. People will then be asking for higher thermal efficiencies in atomic power stations. Those higher thermal efficiencies will surely take us up to higher temperatures, and we shall then be faced with the same problems in atomic power stations as we have in the steam power stations now. This work should be continued with every intent to produce the solutions which will surely be found if the question is studied sufficiently fully.

Dr. **J. Nutting** (Department of Metallurgy, University of Cambridge): As a result of investigations being carried out by Mr. E. Smith, Mr. R. G. Baker, and myself we have found that the creep properties of quenched and tempered 1–3% Cr, 0·8% Mo, 0·8% V steels are greatly dependent upon the formation of a fine dispersion of vanadium carbide, V_4C_3, particles, having a diameter of 200–500 Å. The authors attribute the good creep properties of their steels to the dispersion of the $M_{23}C_6$ type carbide, but in the steels they examined these carbides were large and widely dispersed. I would have thought that such particles would not be effective in promoting good creep resistance. I was wondering therefore if the good creep properties of the authors' steels may be due to a fine dispersion of titanium carbide, which had not been detected.

Mr. **L. C. Southcott** (Superheater Co., Ltd.): To help the user assess the worth of this particular steel, comparisons have been made of scaling properties, creep and rupture strengths at elevated temperatures, and physical properties at room temperature. Of these, the unsatisfactory feature is the low elongation at room temperature, which the authors recognize, since they recommend that the steel should be worked hot.

Such procedure is, of course, common to many other steels in everyday use where the forming operations are too severe to be carried out on the material in its cold state. However, in the case of the 8% Cr–Mo–Ti steel, it would seem that all operations, even those involving comparatively minor deformation, will best be made hot. This would add very considerably to fabrication costs, would reduce output and, further, would call for more critical supervision of actual workshop production.

This material would also, on completion of fabrication processes, which in the case of superheater tubing would include bending and welding, have to be re-heat-treated. In such heat treatment, prevention of distortion of the complex tubular assemblies calls for quite elaborate precautions. Any further essential correction, subsequent to heat treatment, then presents problems.

If the extra costs incurred in fabrication are to be permissible, then the steel and the basic products made from it will have to be considerably lower in price than for austenitic steel designed to perform the same duty.

It would have been most helpful to the user if some relative costs of the materials referred to in this paper had been given, since it would then have been possible to make an assessment as to whether the higher costs of fabrication could be borne in the case of the 8% Cr–Mo–Ti steel.

Personally, I doubt whether the steel proposed will be sufficiently attractive in price to offset fabrication difficulties.

On any steel intended for high-temperature duty, it is necessary for the practical designer to be as fully informed as is possible of the elevated-temperature properties of the steel. Such data are obtained under carefully regulated laboratory conditions, but in practical application the working conditions always show some departure from ideal conditions. In the case of superheater tubes, some may be worked at considerably excess temperatures for short periods, these periods being of an intermittent nature. Prolonged working at temperatures only a little in excess of design conditions must also be accepted.

With any high-temperature superheater tubing, failures may result if the plant is subjected to careless operation, but it must be emphasized that, even with the most skilled operation, some inequalities in temperature distribution are inevitable.

The designer, while recognizing this, finds it most difficult to make an adequate assessment of the margins to allow, since the time at excess temperature and the degree of excess temperature cannot be determined.

In practice, therefore, the designer uses very low stresses and low creep rates for his basic design, knowing then that some abuse is permissible without failure resulting.

Growth of superheater tubes under creep conditions can be tolerated, provided that rupture does not result, and it is for this reason that there is so much interest in rupture data, and for the preference of steels with high ductility at the working temperatures.

Mr. **L. H. Toft** (Central Electricity Authority): In their introduction to the paper, the authors state that a Cr level of 7% or 8% was chosen because they had determined that this is the amount of chromium that is necessary to produce scaling resistance at 621° C (1150° F), which is equivalent to that of a 1% Cr steel at 566° C (1050° F). However, they do not emphasize that the type of scaling test on which this statement is based is carried out in an atmosphere of burnt town gas. It is quite possible that the scaling resistance of steels in the flue gas encountered in coal-fired boiler plant would be different, as the temperatures of these gases in a superheater may be in the region of 1000° C or above. Furthermore, it is probable that the scaling resistance of steels in boilers operating with final steam temperatures of 1050° F (and therefore metal temperatures of about 1150° F) will be affected by the composition of the coal fires and by the combustion conditions in the boiler.

This is another aspect of the general scaling problem and much remains to be done in this field. Whatever the results may be, however, the development of a steel with this chromium content which can be compared with steels of other chromium contents is of great interest.

Mr. **G. A. Mellor** (National Physical Laboratory, Metallurgy Division): I would like to deal with the question of what makes these steels creep-resistant.

The authors say that titanium strengthens the matrix, and they conclude that the carbide $M_{23}C_6$ is an important factor in promoting rupture strength. I would suggest that in strengthening the matrix the 3% of molybdenum is just as important as the 1½% of titanium. Many years ago Austin, St. John, and Lindsay[1] showed that molybdenum was far better than other elements in strengthening ferrite at temperatures up to 538° C. We ought to give credit to molybdenum, but I do agree with Mr.

Gemmill and his co-authors that titanium is also a great ferrite strengthener.

Crafts and Lamont[2] studied the effect of chromium carbides in steels which contained up to 5% of chromium, up to 1% of molybdenum, and up to 1% of vanadium. They showed that the carbides Cr_7C_3 and $M_{23}C_6$ were not very effective in promoting creep resistance because the particles grew with time. As Dr. Nutting has pointed out, they also showed that the vanadium carbide was the main factor in increasing creep resistance because it existed in small particles which were stable over long periods.

What I would suggest is that in this 8% chromium steel the $M_{23}C_6$ is only effective in tests up to a few thousand hours, and that most of the creep strength is really derived from the molybdenum and the titanium in solution. I would welcome the authors' comments on that point.

CORRESPONDENCE

Professor **E. Houdremont** wrote: This paper is of interest to everybody who is concerned with creep-resisting alloys. It is well known that ferritic steels may show properties which are different from austenitic alloys, i.e. in connection with problems of stress corrosion, although ferritic steels themselves can be susceptible to stress corrosion under certain conditions. Sometimes ferritic steels are preferred for the temperature range between 550–600° C not only from the economical point of view, and so the paper may be of value to people who were accustomed up to now to use the 10–12% Cr alloys with the addition of 2% Mo and 0·5% V.

For the general behaviour of precipitation hardening in alloys it would be necessary to point out that the conclusion of the authors cannot be generalized. They say that "the precipitation of Fe_2Ti results in a slight decrease in hardness, indicating that although Fe_2Ti forms a platelike precipitate, the softening of the matrix, by removal of Ti, more than compensates for any precipitation hardening." This statement is not in agreement with our experiences or with other publications.[3] Figures *A* and *B* from the early work of Wasmuht show

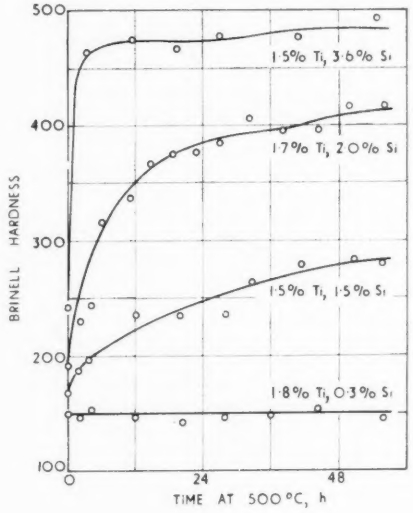


Fig. A—Age hardening in titanium steels at 500° C after quenching from 1000° C

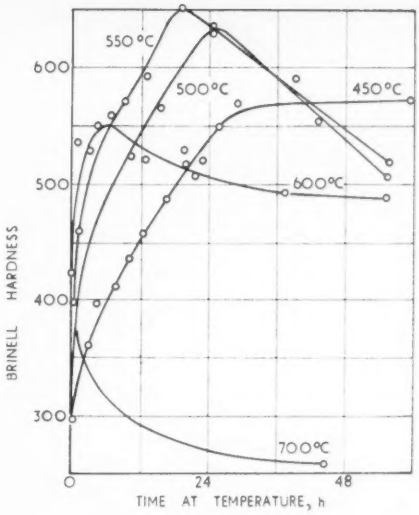


Fig. B—Age hardening at different temperatures in a ferritic steel (0·02% C, 2·15% Si, 7·3% Ti) after quenching from 1250° C

the precipitation effect of Ti in ferritic silicon steels with very low carbon contents. The precipitation effect has its maximum at temperatures of about 500–550° C in wholly ferritic steels. So it is necessary to look at the precipitating effect at such low temperatures where the distribution of the precipitating particles is very fine. At 700° C, where the precipitation particles are large, a softening effect may be concluded. These experiences with precipitation hardening of Fe_2Ti are in good agreement with precipitation hardening in ferritic Fe–Mo, Fe–W, Fe–Co–W, and Fe–Co–Mo alloys[4] in which also the best hardening effects of ferrite are coming out at lower temperatures. It may be that the alloys investigated by Mr. Gemmill and co-workers also show the carbide precipitation effect at lower temperatures, but I believe that at this lower temperature the Ti effect may be of some importance. The conclusion that a precipitation at test temperature is favourable is only valid for short-time tests of about 1000 h. For long-time application, as in the case of power stations, the rupture strength decreases markedly with the beginning of coagulation of the precipitations. For this purpose an equilibrium structure is better. Also precipitation at the temperature of use can cause a heavy embrittlement, as in the case of the Cr–Ni–Mo bolt steel.[5]

AUTHORS' WRITTEN REPLY

The **Authors,** in reply to the discussion, wrote: The paper does show the interaction between precipitation and solid-solution strengthening, and, as Mr. Child points out, this interaction is complicated. One cannot necessarily conclude, as he does, that solid-solution strengthening is the main factor, because a reduction of Ti in solution by the precipitation of Fe_2Ti also causes less precipitation of $M_{23}C_6$. Also, the $M_{23}C_6$ must precipitate during test in the solution-treated condition and therefore it is not true to conclude that precipitation of this phase only produces a 5% increase in rupture strength. In fact, the interaction between titanium in solid solution and its effect on precipitation hardening is so complex that at present it is almost impossible completely to separate the two effects.

Fig. C—Ageing in a typical 8% Cr–Mo–Ti steel × 16,000

With regard to the ferrite content, our investigations did show that wholly ferritic steels were to be preferred, at least as regards this basic type of Cr–Mo steel. We would agree, however, with Mr. Child that other alloys of varying composition can give the same creep strength with varying ferrite contents. We would also agree with the general remarks concerning higher Cr steels possessing adequate creep strength. However, the increased Cr content has to be compensated for by increased alloy additions. Consequently, it was felt that no useful purpose could be achieved by increasing the Cr content above that which would give adequate scaling resistance coupled with the required level of high-temperature strength.

Dr. Allen considers that precipitation prior to testing would decrease primary creep, which is true, but it should also be remembered that precipitation prior to testing may often give more rapid overageing and hence reduce the overall life of the components. The very fact that a steel does show precipitation hardening results in the natural consequence that after several thousand hours overageing occurs, with a decrease in creep resistance as Mr. Mellor suggests. The dependence of this overageing on the solid-solution effect of titanium, however, is most marked, and we would agree that both Mo and Ti are necessary, be it either as solid-solution strengtheners, or as participants in the $M_{23}C_6$ precipitation. If one or both are omitted, the steel completely loses its high strength. Crafts and Lamont indeed showed that $M_{23}C_6$ was a poor strengthening carbide, but they were dealing with the tempering of a martensitic steel in which it is formed as a final product from or by means of other intermediate products. Its effects therefore are probably different when, as in the present context, it precipitates directly from ferrite.

Dr. Nutting raises the point of whether the creep properties are not the result of a fine dispersion of titanium carbide. Subsequent to the work reported in the paper we examined, by electron microscopy, the progress of ageing in a typical 8% Cr–Mo–Ti steel, using a shadowed two-stage Formvar–carbon-replica technique. No evidence was found of fine titanium carbide, but, as Figs. *C* and *D* show, the $M_{23}C_6$ formed as very thin plates, which were probably only of the order of 500 Å thick, but some thousands of angstroms long. These were probably quite sufficient to give good strength properties by dispersion hardening even though too large to produce coherency hardening. No work, however, has been carried out using direct carbon-extraction replicas.

The authors cannot agree with Professor Houdremont's suggestion that Fe_2Ti might form a hardening precipitate at lower temperatures than 750° C. As shown in the paper, the *C* curve for Fe_2Ti indicates that for all practical considerations Fe_2Ti would not form much below a limiting temperature of 650° C at the least. In the results he quotes due to Wasmuht, the precipitation effects in Fig. *A* would appear to be due as much to silicon as to titanium, whilst in Fig. *B* the steel is very rich in titanium (7·3%) and contains no other carbide formers such as Cr and Mo. The authors doubt the relevance of these results to the interpretation of the work in the paper.

Turning to the more commercial interest, we agree with Mr. Toft's remarks concerning scaling and the need for more work in this field. However, we feel that the difficulty in simulating service flue gas and dry-steam conditions are very nearly insuperable on a laboratory scale, and that field trials are the only way of obtaining this information.

Mr. Southcott has also raised the question of low ductility values and the need to provide adequate margins of safety for the engineers installing the plants.

We have evidence that the tensile ductility is markedly affected by the titanium content and it is possible, by slight modification to the titanium content, to obtain a good level of tensile ductility with little loss in rupture strength. In Table X of the paper the rupture properties of two commercial casts are shown; it is to be noted that under a stress of 11·0 tons/in² cast B.6860 (1·45% Ti) gave a rupture life of 492 h at 621° C, while cast A.30292 (1·18% Ti) ruptured in 462 h at the slightly higher temperature of 625° C. The room-temperature tensile ductilities of these two casts in the solution-treated condition were as follows:

	B.6860	A.30292
Ti content, %	1·45	1·18
Elongation on $4\sqrt{A}$, %	6·4	31·5
Reduction of area, %	9·0	56·6

Fig. D—Ageing in a typical 8% Cr–Mo–Ti steel × 16,000

From a more general viewpoint it is our opinion that increased high-temperature strength is only likely to be obtained at the expense of other properties, e.g. ductility and impact, and it is unreasonable to ask, when strength levels are required higher than those of materials in present use, that the new materials should have other properties similar to existing alloys. In other words new materials require new and, moreover, more carefully controlled, fabrication techniques if they are to be used to advantage, and as alloys of greater and greater strength are developed so the use of careless operating and fabrication methods become less tolerable.

It is the authors' opinion that new alloys should first be developed to obtain the strength requirements, and then as much development work should go into fabrication methods. This, of course, places some of the onus on the engineering firms concerned.

With regard to the economics of the steel, it will, as Mr. Southcott says, be initially less costly than stainless 18/13/1. In general, it can be fabricated in a similar manner to stainless, and presumably at a similar cost. It remains therefore to establish whether the cost of extra post-fabrication heat treatment can be offset by the initially lower cost of the alloy.

Finally, the authors would like to thank all who contributed to the discussion.

REFERENCES

1. C. R. Austin, C. R. St. John, and R. W. Lindsay: *Metals Technology*, 1945, vol. 12, Techn. Pubn. 1837.
2. W. Crafts and J. L. Lamont: *Trans. Amer. Inst. Min. Met. Eng.*, 1950, vol. 188, pp. 561–574; *J. Met.*, 1950, vol. 2, Mar.
3. R. Wasmuht: *Kruppsche Monatshefte*, 1931, vol. 12, pp. 159–178.
4. W. Koster: *Arch. Eisenhüttenwesen*, 1932–3, vol. 6, pp. 17–23.
5. F. Wever, A. Krisch, and H. J. Wiester: *Ibid.*, 1955, vol. 26, pp. 463–474.

JOINT DISCUSSION ON ALLOY STEELS

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parentheses):

- **"The Tempering and Nitriding of Some 3% Chromium Steels,"** *by C. C. Hodgson and H. G. Baron* (1956, vol. 182, March, pp. 256–265)
- **"Some Experiments on the Composition of Carbides in Low-alloy Steels,"** *by J. R. Bowers* (1956, vol. 183, July, pp. 268–274)
- **"Bainitic Retained Austenite,"** *by J. A. Cameron* (1956, vol. 183, July, pp. 260–267)
- **"The Temperature of Formation of Martensite and Bainite in Low-alloy Steels. Some Effects of Chemical Composition,"** *by W. Steven and A. G. Haynes* (1956, vol. 183, Aug., pp. 349–359)
- **"The Tempering of Plain Carbon Steels,"** *by E. D. Hyam and J. Nutting* (1956, vol. 184, Oct., pp. 148–165)
- **"Alloy Carbides Precipitated During the Fourth Stage of Tempering. An Electron Microscopic Examination,"** *by K. Kuo* (1956, vol. 184, Nov., pp. 258–268)

Mr. **H. G. Baron** (Ministry of Supply) presented the first paper, Dr. **J. R. Bowers** (British Non-ferrous Metals Research Association) the second, Mr. **J. A. Cameron** (English Electric Co., Ltd.) the third, Mr. **A. G. Haynes** (Mond Nickel Co., Ltd.) the fourth, Dr. **J. Nutting** (Cambridge University) the fifth, and Dr. **Bowers** the sixth (for the author).

Mr. **Cameron,** in introducing his paper, pointed out that Fig. 7 should refer to specimen *Y* and not specimen 7. In the caption to Fig. 9 the term "W.Q." should not appear.

Mr. **J. E. Russell** (English Steel Corp., Ltd.): The papers before us represent a remarkably wide variety within the general framework of physical metallurgy. Although they contain many possible subjects for discussion, I propose to confine my remarks to three points. The paper by Dr. Steven and Mr. Haynes is, I should think, the last word on the subject of formulæ for M_s, and they have thrown in formulæ for M_f and bainite temperatures as well for good measure. We must be grateful to them for tying up so neatly a matter which has been unnecessarily the subject of so much difference of opinion.

Their formulæ have been familiar to a number of us for well over a year, since they were given in a report to the B.I.S.R.A. Isothermal Transformation and Hardenability Group, and we have had plenty of opportunity of trying them out. Our experience has undoubtedly confirmed their M_s and B_s formulæ to well within the authors' stated accuracy. Above about 5% nickel, however, the experimental values of M_s consistently fall below those calculated, but the formula for M_s appears to be quite adequate for chromium content, certainly up to about 8% and possibly higher, other elements being fairly small.

Their value of the M_s–M_f range, given as constant at about 215° C, is also confirmed by our experience, although for very highly alloyed ferritic materials, where M_s falls to the region of below 50° C, the M_s–M_f range appears to narrow down to the order of 150–160° C.

There are four papers discussing carbide distribution and composition, all of which are of a very high standard and on which I do not propose to comment in detail, but I feel rather uneasy about one factor common to them all, the tendency to regard hardness as the principal mechanical property indicating carbide changes. The hardness test is an easy one, but it may in fact cloak or even obliterate processes which are shown up by yield or impact results. Hyam and Nutting, for example, in deriving their equation (7) from the Fisher, Hart, and Pry relation between critical yield stress and various structural parameters, tacitly equate the ultimate tensile stress to the yield stress, although as it happens, the error is small, since the yield ratio of carbon steels does not vary greatly between 0·1% and 0·9% carbon.

The same sort of thing is repeated in the papers by Kuo and Hodgson and Baron, and where vanadium is present this may be particularly dangerous. Take, for example, a steel of the DTD 551 Cr–Mo–V type, similar to Hodgson and Baron's steel *D*. Full mechanical tests at different tempering temperatures on test-piece-size bars, about 0·6 in. diameter, after oil-hardening gave the results shown in Fig. *A*. The tensile-strength curve more or less follows the same course as the hardness results given by Hodgson and Baron in their Fig. 7, but the limit of proportionality shows the remarkable trough about 500–550° C which is partly reflected in the 0·05% proof stress.

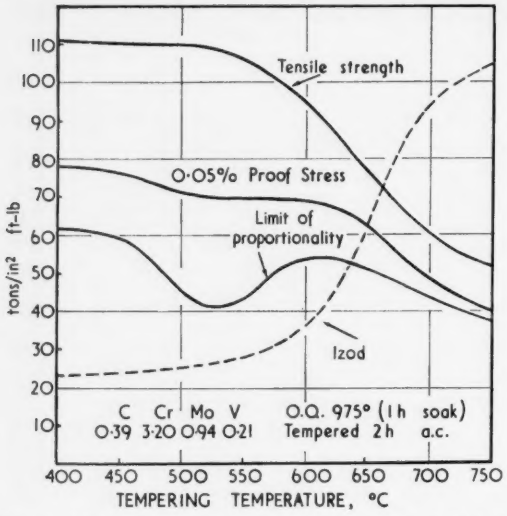


Fig. A—Mechanical tests on 1⅛-in. bars of a Cr–Mo–V steel tempered at different temperatures

Fig. B—Carbon replica of 9% Cr, 0·38% V, 0·22% C steel A tempered 1000 h at 400° C × 24,000

Where the secondary hardening, or retardation of softening, is caused by precipitation of vanadium carbide, in steels with little or no chromium, the limit of proportionality and proof stress follow the increase in hardness, and the Izod shows a corresponding trough, as described in the paper by Burton and Russell to the Institute[1] as long ago as 1938. Here, however, the Izod curve shows no anomaly, and the region of greatest retardation of softening, 480–600° C, practically coincides with the trough in the limit of proportionality curve.

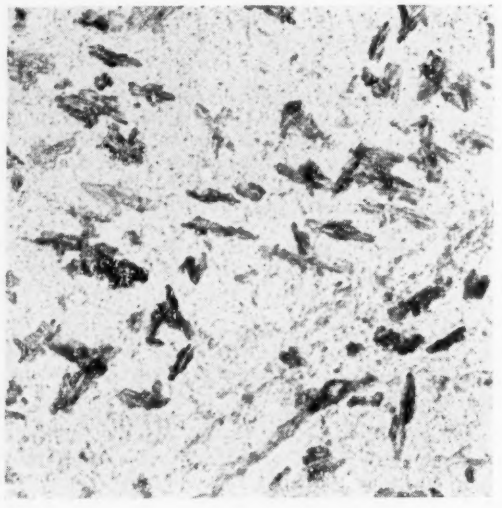
This appears at first sight to be strong evidence against Crafts and Lamont's idea, quoted by Hodgson and Baron, of a fine dispersion of V_4C_3, too small to be detected by normal methods, despite the picture shown by Dr. Nutting in discussion of the paper by Gemmill and others, showing vanadium carbide precipitating out in an 8% Cr steel.

Personally, I favour the authors' suggestion, following that of Baluffi, Cohen, and Averbach, that the presence of vanadium merely retards the formation of chromium carbide Cr_7C_3, the drop in limit of proportionality at 500° C being associated with the coarsening of the low-temperature carbide, presumably iron carbide, in the absence of the onset of chromium carbide. About 530–600° C the delayed change to Cr_7C_3 gradually sets in, with an associated increase in the limit of proportionality, the subsequent drop being again due to coarsening of these chromium carbides.

The retardation of softening at 500° C would then be due, in this analysis, to the plastic working during pulling the tensile or making the hardness test, causing precipitation of the chromium carbides typical of a few degrees higher temperature in the unstrained state. Glen, in 1952, demonstrated that this sort of phenomenon could be observed even in carbon or carbon–molybdenum steels tensile-tested at various temperatures, and this mechanism seems quite feasible for the rather unstable conditions which must be operative on this steel in the 500–600° C region.

Professor **R. W. K. Honeycombe** (University of Sheffield): I read Mr. Kuo's paper with great interest as Mr. A. K. Seal and I have been investigating the phenomenon of secondary hardening by similar means at Sheffield. While the present author has relied primarily on chemical extraction of the carbides from the ferritic matrix, we have found that the use of carbon-extraction replicas, in which the carbides are in the geographically identical positions which they occupied in the steel, is more satisfactory when the carbides are in the earliest stage of formation.

We are in complete agreement with the view that secondary hardening arises from an age-hardening reaction in which the alloy carbides are the precipitating phases. Mr. Kuo points out the close resemblance of vanadium, molybdenum, and titanium carbide particles in the early stages of the precipitation, but he considers the chromium-carbide formation involves a different nucleus because of differences in the carbide shape and its tendency to coarsen. While we would agree that there are circumstances in which Cr_7C_3 can form directly



↑ grain-boundary region

Fig. C—Carbon replica of steel A after 10 h at 500° C × 56,000

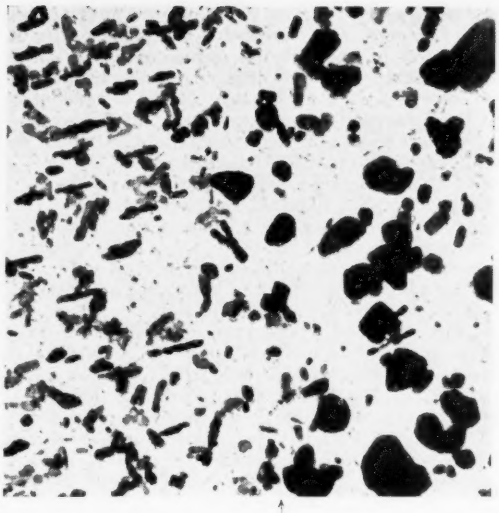


Fig. D—Carbon replica of steel A tempered 1000 h at 500° C × 56,000

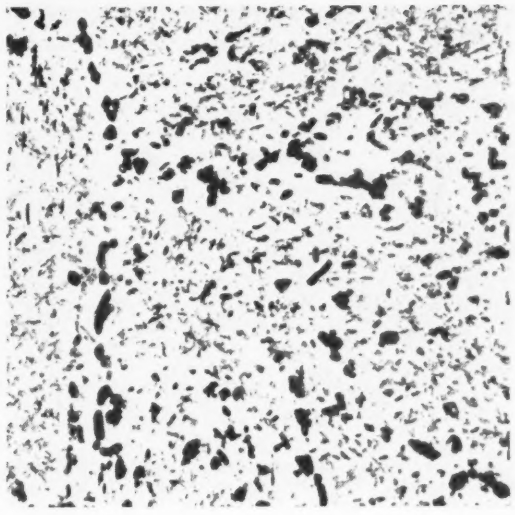


Fig. E—Carbon replica of steel A, tempered 1000 h at 500° C, showing massive Cr_7C_3 precipitate at grain boundaries × 24,000

from Fe_3C, we have evidence that in the tempering of low-carbon chromium steels, Cr_7C_3 is formed principally by separate nucleation and not by nucleation within existing Fe_3C particles. In our replicas we could distinguish clearly between the two carbides, and there was definite evidence that the Fe_3C went into solution while the Cr_7C_3 nucleated separately in a very fine form which, however, rapidly coarsened. The first detected Cr_7C_3 was much smaller in size than the co-existing Fe_3C, and obviously had formed independent of it.

Figure *B* is a carbon replica of a steel containing 9% chromium (0·38% V, 0·22% C). It has been tempered 1000 h at 400° C. Throughout the structure, cementite rods can be seen which are thinning down at the ends and clearly going into solution. At this stage the chromium-carbide precipitate is not detectable.

The structure produced after 10 h at 500° C (Fig. *C*) is rather different. The background has a very fine mottled appearance; this is the beginning of the chromium-carbide precipitation, which is more pronounced at the grain boundaries.

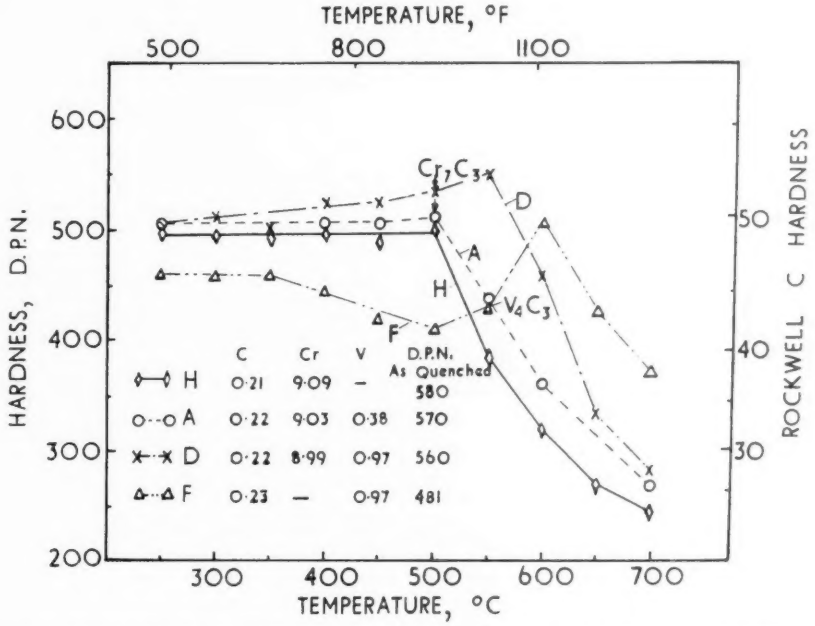


Fig. F—Hardness on tempering of several Cr–Mo steels, tempering time 1 h. The arrows indicate the points at which alloy carbides were first detected

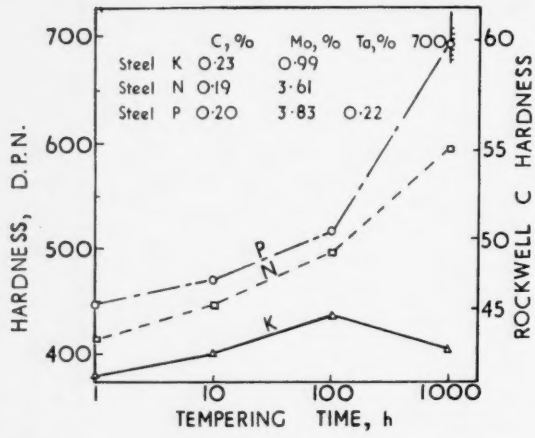


Fig. G—Hardness on tempering of three molybdenum steels. Tempering temperature 500° C

The position after 1000 h at 500° C is shown in Fig. *D*; in the centre of the grains some residual cementite rods can be seen, but in the boundary regions there has been definite growth of the chromium carbide, Cr_7C_3 (Fig. *E*). Fine particles of chromium carbide are also present in the centre of the grains. There seems little doubt that chromium carbide is nucleating separately. This viewpoint is further supported by the fact that we were able to obtain secondary hardening in a 9% Cr, 0·38% V steel after long periods of tempering at a relatively low temperature. This secondary hardening peak was substantially increased by the addition of 1% vanadium although the precipitating phase was still Cr_7C_3-type carbide, (Fig. *F*).

This brings me to the question of the origin of the hardening. Mr. Kuo has mentioned coherent hardening and dispersion hardening, but I think he has failed to distinguish the stages at which each is likely to occur. For example, he states that the Mo_2C, VC, and TiC threads, precipitating at 500–600° C, satisfy the requirement for dispersion hardening, whereas I feel that these are precisely the conditions under which coherency hardening is developed to a maximum. Coherent hardening arises from the stress fields set up around small particles which still have atomic coherency with the matrix along certain atomic planes. These stress fields increase the effective diameter of the particle, as they too can hinder the movement of dislocations. Particles which have close orientation relationships with, and lie along planes of, the matrix, as the thread-like particles of Mo_2C, VC, and TiC appear to do, are likely to be coherent with the matrix. The initial mode of formation by segregation of solute atoms in the matrix implies coherency in the early stages, and it would appear reasonable to suppose that this exists up to about the peak hardness, although of course there is no direct evidence to confirm this.

Dispersion hardening, on the other hand, relies simply on the particles themselves to block the movement of dislocations and is obviously more effective the more numerous the particles. If we are considering an alloy of constant composition, then the dispersion hardening is greater the higher the degree of dispersion. I feel that in the alloy steels, once the peak hardness has been passed, we are relying simply on dispersion hardening, and the important point then is the rate of growth of the particles, as the coarse particles grow at the expense of the fine ones. This process is controlled by the rate of diffusion of the alloying elements in the carbide. Here probably is the explanation of the behaviour of the chromium steels. Initially Cr_7C_3 is precipitated, but the coherency stresses are small and the hardening is slight. Presumably chromium diffuses much more readily in ferrite at 550° C than does Mo, Ti, or V, so the Cr_7C_3 rapidly coarsens and the hardness drops.

In our work at Sheffield we have attempted to see whether we can alter the hardening characteristics of these carbides, and we have found that quite spectacular increases in the peak hardness can be obtained by small alloying additions of the carbide-forming elements. For example, to a 0·2% C, 3·8% Mo steel we added 0·22% Ta; Fig. *G* shows clearly the marked effect on the approach to peak hardness at 500° C. Steel *N* has developed a hardness of 600 DPN, whereas steel *P* has risen to 700 DPN. It appears that part of this effect is undoubtedly due to the separation of a separate TaC phase, but it is likely that, in addition, the coherency stresses of the Mo_2C particles have been increased. Tempering at 700° C still results in marked difference in hardness which we attribute to differences in the state of dispersion of the carbides. Electron-microscopic examination confirms this view.

To summarize, the deliberate modification of the carbide phase or phases by small additions of carbide-forming elements is capable of producing marked changes in mechanical properties. These are achieved by three mechanisms: (*a*) increase of coherency stresses between the carbide particles and the matrix, (*b*) increased stability of the existing carbide dispersion (by influencing diffusion rates) and (*c*) formation of a second very fine, stable carbide precipitate (e.g. TaC, NbC).

Dr. **F. W. Jones** (Brown-Firth Research Laboratories, Sheffield): The paper by Dr. Steven and Mr. Haynes is so good that it is difficult to find anything to criticize, but I have two comments to offer.

First, at Firth Brown we have done a fair amount of work on transformation during continuous cooling, in connection with the normalizing of large forgings. We find that at the relatively slow cooling rates employed (generally 30° C/h or slower through the bainite range), our experimental results are generally in reasonable agreement with the bainite transformation range predicted using the authors' factors, even though the latter were determined for isothermal conditions. Presumably the fair agreement arises from the fact that, at such slow cooling rates, the bainite transformation becomes more or less temperature dependent rather than time dependent. However, there will be exceptions, notably En40C, which Mr. Cameron has been discussing.

The other point concerns the relative effects of the different alloying elements on the martensite and bainite transformations. Dr. Steven's and Mr. Haynes' factors are tabulated below:

	Martensite	Bainite
Carbon	474	270
Manganese ...	33	90
Molybdenum ...	21	83
Chromium ...	17	70
Nickel	17	37

Carbon, being an interstitial element and being precipitated in the bainite but not the martensite transformation, might be expected to behave differently in its effects on the two transformations. It is tempting to think that the effects of the other alloying elements might be relatively the same in the two transformations, and in fact we can make the ratio constant without considerable alterations to the authors' figures:

	Martensite	Bainite
Manganese ...	30	97
Molybdenum ...	20	75
Chromium ...	19	62
Nickel	14	45

In each case the bainite factor is 3·2 times the martensite factor. Comparing these figures with the authors' figures, it will be seen that the alterations are quite small, possibly almost within the experimental error.

Dr. **G. Lucas** (Brown-Firth Research Laboratories): I should like to make a short contribution to Mr. Cameron's paper. The presence of retained austenite in steel can be of considerable importance, and the author's observations on the formation and subsequent conditioning of retained austenite in these En steels are welcome.

There are two aspects of the practical side of the work which I should like to discuss. Neither affects the qualitative conclusions of the paper but they are worth some attention. The first is important in considering the authors' Table VII, where the amount of retained austenite obtained in different En steels is compared, and it is the considerable effect the surface condition of the specimen may have in the X-ray determination of retained austenite.

Determination of the amount of retained austenite on both electropolished and mechanically polished surfaces readily shows the necessity for the former. Perhaps the author would tell us what was the surface condition of his specimens.

Mr. Cameron also gives analytical results on carbide extracts. Unfortunately, he does not report any X-ray examination of the residues. Was this carried out?

Since the extraction of carbides can be rather a precarious process with low-alloy steels, decomposition during extraction occurring in certain circumstances, an X-ray examination of the extract is highly desirable.

On one minor point of detail, I presume that the ordinates in Figs. 2–6 should be multiplied by 10^{-4}.

Dr. **K. W. Andrews** (United Steel Cos. Ltd., Rotherham): As Mr. Russell has said, these papers cover a very wide range of interests. It would be wrong for me to try to discuss more than one or two small matters, and I will confine my remarks to points in which I am most interested, in particular the carbide phases, their constitution, and relation to the properties. My colleague, Dr. Hughes, and I have done a lot of work on those lines and some of our efforts were discussed earlier.

We have made particular use of these extraction methods, followed by X-ray analysis, and they have come in for a little criticism in this discussion. Mr. Kuo points out that the methods are liable to exclude the smallest precipitated particles such as we find at the earliest stages. We are inclined to agree with that observation, except that with suitable separation techniques we believe that the X-ray diffraction method will take us down a long way. We are, however, aware of the advantage of an electron microscope in this sort of work.

I should like to refer to only one recent investigation which we have carried out. It illustrates that methods using separated particles can give valuable information, particularly if rather more account is taken of the time axis than some of these investigations have done. Time at temperature can lead to interesting changes in carbides and some of the papers have touched upon these effects, but little is known about the behaviour of many different kinds of steel in which such changes could be important. The steel to which I shall refer is rather close in composition to steel *H* in the paper by Hodgson and Baron. They are not identical, but the composition is similar, viz. 2¼% Cr–1% Mo–0·1% C. On following the type of carbide formed in this steel over periods of time at different temperatures between 550–700° C, we found that there is a general scheme of this kind:

$$\text{Matrix} \nearrow Fe_3C \longrightarrow Cr_7C_3 \longrightarrow M_{23}C_6 \searrow$$
$$\text{Matrix} \searrow Mo_2C \longrightarrow M_6C$$

The Fe_3C type of carbide is followed by the Cr_7C_3 type and that is followed by $M_{23}C_6$.

The lower sequence ($Mo_2C \rightarrow M_6C$) was obtained in this instance only at 700° C. At that temperature the upper sequence was followed through very quickly. At lower temperatures the tendency is for the upper of the two sequences to predominate, so that at 550° C Fe_3C lasts for several hundred hours before any Cr_7C_3 is found. Above 600° C, Fe_3C forms first, but disappears rather rapidly and Cr_7C_3 takes its place. These investigations are continuing and other points of interest may arise.

Dr. Bowers' paper refers to the value of attempting to estimate composition changes in the phases. We need more work to give accurate measurement of the composition of the phases as they go through the changes. There is a great deal of useful information in the literature which has not received the attention it deserves.

As for the question whether certain carbides nucleate separately, we think, although we may be wrong, that if Fe_3C can be precipitated and remain present for a number of hours, then we find Cr_7C_3 taking its place between 400° and 700° C, so that at no time do they coexist over long periods of time. The Cr_7C_3 must be nucleated in this instance by Fe_3C and does not form separately itself.

Another point to bear in mind is that the end product at 550° C may never have been reached although ultimate equilibrium is not necessarily the same as at 700° C. The time axis must be taken into account, although many commercial steels may be used without requiring to be heated for such long times. On the other hand we have been able to show that steels which are in service for times longer than 100,000 h at, say, 550° C, may still be a long way from final equilibrium.

Turning to the paper by Hodgson and Baron, have the authors come across any evidence of the occurrence or the influence of chromium nitride, Cr_2N, in the nitrided cases? We have found this constituent in steels containing chromium without nitriding treatment and are beginning to suspect that it is one of the constituents which must be taken into account. Whether it takes a very active part in metallurgical changes or whether it behaves mostly as an inert inclusion may depend on the type of steel and the amount of the nitride present.

Mr. **D. M. McLean** (National Physical Laboratory, Metallurgy Division): To retain the peak hardness it is necessary to stop the precipitate particles growing beyond the critical size. The driving force for growth comes from the energy of the interface between particle and matrix. The rate of growth must be some function of the boundary interface energy *times* the rate of diffusion ($\lambda \times D$). The peak hardness would therefore be pushed to higher temperatures by reducing the interface energy. As the precipitates are coherent we should be able to control the interface energy to some extent. The interface energy then depends on the difference between the lattice parameters of precipitate and matrix, and can be varied by adjusting the lattice parameter of the matrix by adding suitable solid-solution elements.

Dr. Nutting argued that the carbide particles control the ferrite grain size. He explained this by suggesting that the ferrite grain size was controlled by the rate of diffusion of iron, which also controls the rate of growth of the carbide particles. Accepting the first part of the argument, do we need the second? For if the car-

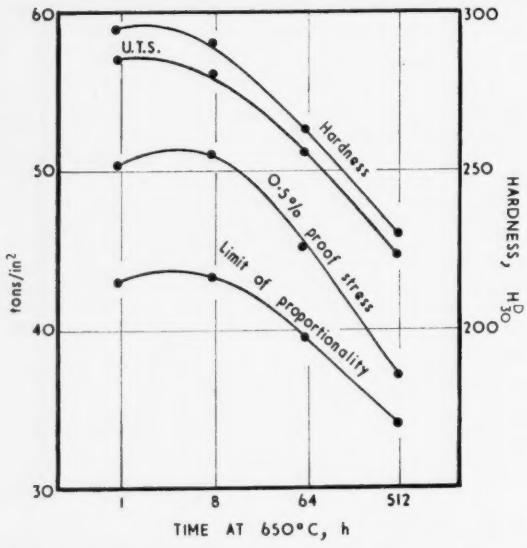


Fig. H—Hardness and tensile characteristics of a 0·1% C, 0·5% Mo, 0·25% V steel, normalized from 1000° C, tempered at 650° C

bide particles control the ferrite grain size, then the ferrite grains, if left to themselves, would go faster than permitted by the carbide particles. This is probably so since there is fair evidence now that the factor controlling the rate of grain growth is self-diffusion along the grain boundaries, which at the temperatures in question is faster than bulk self-diffusion, which Dr. Nutting suggests controls the rate of growth of carbide particles.

Mr. **F. G. Haynes** (Metropolitan-Vickers Electrical Co., Ltd.): I should like to support Mr. Russell's plea for more tensile testing to supplement hardness data. We have carried out hardness and tensile tests on a steel containing 0·1% C, 0·5% Mo, and 0·25% V, normalized from 1000° C and tempered at 650° C for a range of times. The results are shown in Fig. *H*.

The gradual convergence of the curves for the 0·5% proof stress and the limit of proportionality shows the decrease of initial strain-hardening rate with increased tempering. This is a characteristic of over-ageing which is not brought out by simple hardness testing.

Unfortunately, with this material the curve of limit of proportionality gives no premonition of softening, such as Mr. Russell has quoted for a Cr–Mo–V steel.

AUTHOR'S REPLIES

Dr. **Nutting**: Mr. E. Smith and I have been investigating the metallographic changes which accompany the tempering of steels containing chromium, molybdenum, and vanadium. The results we have obtained agree in general with those given by Mr. Kuo, and support the view that in a steel containing 0·2% carbon and 3% chromium the chromium carbide is nucleated close to the initially precipitated iron carbides. In steels containing both chromium and vanadium we have found that vanadium carbide is the first alloy carbide to precipitate and that only at high tempering temperatures is chromium carbide formed, chiefly at the ferrite grain boundaries. This sequence of changes was also found in steel containing 0·17% carbon, 7% chromium and 0·8% vanadium. The microstructure of this steel after tempering for 1 h at 700° C is shown in Fig. *I*. The large particles are Cr_7C_3 whilst the small particles are V_4C_3. These have been identified both by their morphology and by selected-area electron diffraction. Our results therefore do not agree with those quoted by Professor Honeycombe, but we would interpret his electron micrographs quite differently, as we think the particles formed within the ferrite grains are V_4C_3, not Cr_7C_3. If the secondary hardening of the 9% Cr steel quoted by Professor Honeycombe is increased by increasing the vanadium content from 0·38% to 1%, this must surely indicate that the precipitating phase is V_4C_3 and not Cr_7C_3.

We would agree with Mr. Russell that the presence of vanadium in low-chromium steels retards the precipitation of chromium carbide. However, we believe the reason to be simply that the vanadium and carbon react to form V_4C_3; therefore only the carbon in excess of that required to form V_4C_3 is available for the formation of Cr_7C_3.

We do not entirely agree with the views put forward by Dr. McLean on the respective rates of growth of the carbide particles and the ferrite grains. If the carbide particles tended to grow rapidly, and the grains slowly, then grain growth would not be hindered by the particles at the boundaries. Therefore on tempering we should expect all steels, independent of carbon content, to have approximately the same hardness after a given tempering treatment. But this is obviously not the case. Dr. Hyam and I believe that the growth of the ferrite grains is hindered by the carbide particles, and therefore as the particles grow larger the grains may grow larger.

Mr. J. Coiley and I have obtained further evidence to support this view. A plain carbon steel has been tempered, cold-worked, and then retempered. By this treatment it has been possible to make the grain boundaries break away from the restraining influence of the carbide particles. Rapid grain growth then occurs and the steel softens faster than a corresponding specimen which has not been cold-worked. The hardness

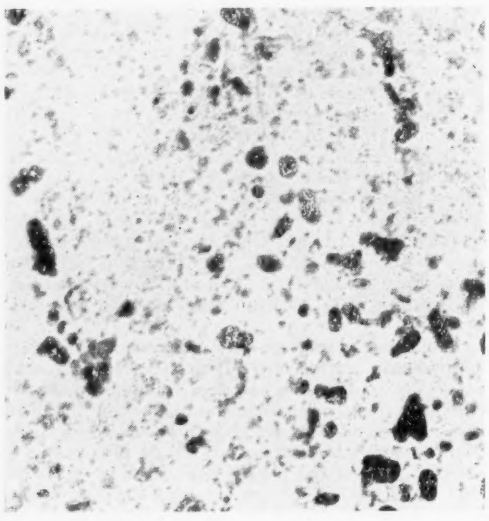


Fig. I—Microstructure of a 0·17% C, 7% Cr, 0·8% V, 0·5% Mo, 0·6% W, steel, quenched and tempered for 1 h at 700° C. The large particles are Cr_7C_3, the small particles are V_4C_3. Direct carbon-extraction replica × 25,000

of the steel is found to be related to the ferrite grain size and not to the carbide distribution, which does not change much during the heat treatment.

Mr. **A. G. Haynes:** I wish to thank Mr. Russell for his comments concerning the accuracy of the M_s formula when applied to steels having nickel and chromium contents greater than 5% and 3·5%, respectively. We have examined M_s temperature data for low-carbon nickel-containing steels and, contrary to his experience, we have found good agreement between calculated and experimentally determined values for steels containing below 15–20% nickel. The M_s temperatures obtained by Payson and Savage from the examination of a series of steels containing 0–5% manganese, nickel, or chromium are also in good accord with values calculated from the formula.

Mr. Russell quotes a value of 150–160° C for the extent of the M_s–M_f range in high-alloy steels, compared with our value of 215 ± 15° C. Although this difference may appear great at first sight, it should be realized that the latter stages of martensite formation are extremely sluggish and that a temperature decrease of the order of 45–75° C is required to effect the decomposition of the last 1% of austenite.

Dr. Jones has made a most interesting observation concerning the relative effects of alloying elements on martensite and bainite formation. It is conceivable that some relationship should exist between the alloy factors in the two formulæ, but much arithmetic will be involved to establish whether the modified factors he suggests will seriously affect the accuracy of the formulæ.

The results of some work carried out in the Birmingham Laboratory of The Mond Nickel Co., Ltd., suggest that bainitic retained austenite is most likely to be present in steels which exhibit a range of incomplete bainite formation at temperatures above M_s. From a comparison of the formulæ for determining M_s and B_f temperatures from chemical composition, it is possible to establish the amount of alloy element which will apparently suppress the B_f temperature below M_s. For example, incomplete bainite formation above M_s is obtained in medium-carbon chromium–molybdenum steels containing more than 3% chromium, and in medium-carbon nickel–chromium–molybdenum steels containing more than 4% nickel.

Mr. **J. A. Cameron**: I should like to thank Dr. Lucas for his comments; in reply to the points raised I must state that the samples for X-ray determination of retained austenite were mechanically polished, and secondly, no X-ray examination of the carbide residues was carried out.

Dr. **E. D. Hyam**: Mr. Russell referred to the universal use of hardness tests and our results. He is quite right that we have related our results to the U.T.S. and not the yield point, but we feel that any error involved will be small. Hardness testing has a fundamental relationship to the stress/strain curve.

There is no particular virtue in choosing the yield point, because the Fisher, Hart, and Pry formula is based on the stresses required to push dislocation loops round the particles. It is therefore the flow stress rather than a yield stress which must be considered. The fact arises that any point of equal strain along the stress/strain curve can be taken.

CORRESPONDENCE

Dr. **M. R. Myerson** and Mr. **S. J. Rosenberg** (U.S. National Bureau of Standards) wrote: A few years ago we made a study of the effect of certain heat-treating variables upon the start and progress of the martensite transformation in two steels of 0·49% C [2,3] and a high-purity iron–carbon alloy of 0·50% C. It is of interest to discuss the work of Dr. Steven and Mr. Haynes in the light of our findings.

We have used the authors' formula (M_s (° F) = 1042 − 853 C − 60 Mn − 30 Cr − 30 Ni − 38 Mo) to calculate the M_s of our steels and are gratified to find that our experimental values are in excellent agreement with the calculated values, as shown by the following:

	M_s (° F)	
	Experimental	Calculated
NBS Steel M 179	581	576
NBS Steel M 182	577	575

These experimental values were obtained on the steels as austenitized at 1475° F with a resultant grain size of A.S.T.M. 8. However, when austenitized at successively higher temperatures, with concomitant increase in grain size, the M_s increased to 621° F at grain size 2–3. The data given in the cited references establish rather conclusively, we believe, that the austenite grain size has a definite effect upon the M_s. In view of this, we believe that any empirical formula for the computation of M_s must be modified to include a factor for grain size. Even though the authors' Fig. 2*f* shows generally good agreement between their calculated and experimental values of M_s, it is possible that even better agreement might have been obtained if they had taken into account the variable of grain size.

As a further indication of the accuracy of the value given for carbon in the authors' formula, unpublished data obtained in our laboratory show an M_s of 623° F for a high-purity iron–carbon alloy of 0·50% C. The calculated value is 620° F. This alloy had an austenite grain size of 6. When treated to establish a coarser grain size, the M_s was raised.

Another real effect of austenite grain size noted by us was that the rate of formation of martensite below the M_s (i.e. the percentage of martensite formed per degree drop in temperature) was lower the larger the austenite grain size. This effect was rather marked until about 25% of martensite had formed.

We note that the authors give rather high M_f values (room temperature or higher) for their selected steels, and also that X-ray examination of some of them revealed no retained austenite, provided that the steels had been quenched to 100° C or lower. This latter observation in particular was quite surprising to us as we found retained austenite in our plain carbon steels after quenching to as low as − 320° F.

The persistence of retained austenite in our experimental steels effectively prevented the determination of the M_f, which obviously must be lower than − 320° F in these steels. Furthermore, as the rate of transformation of austenite to martensite became exceedingly slow after about 90–95% of martensite had formed, it was not practicable to select, with any degree of accuracy whatever, even an arbitrary criterion of M_f such as, say, 99% transformation.

The steels used by the authors for determining the martensite formation range varied in carbon from 0·32% to 0·44%, and contained appreciable amounts of alloy. The analyses are such that we would expect, on the basis of our experience, that appreciable amounts of retained austenite would exist at the temperatures given as the M_f for the various steels.

Dr. **E. E. Underwood** (Battelle Memorial Institute) wrote: The paper by Messrs. Hyam and Nutting is of great interest because it is one of the few to attempt a quantitative measurement of the volume fraction of very small particles. A similar attempt was made at the Battelle Memorial Institute in 1955[4] with high-purity alloys of aluminium and 2% copper. The results of the authors with tempered steels were also substantiated in the Battelle study with aluminium–copper alloys; in both cases the measured volume fraction of

the small precipitate particles was greater than that expected on the basis of the phase diagram.

Unlike the present authors, however, the Battelle results were accepted as correct until proven guilty. A substantial measure of confirmation of these anomalously high amounts of precipitate was found from diverse sources. Guinier,[5] Hardy,[6, 7] Dorn,[8] Phillips and Brick,[9] Roberts[10]—to quote a few—have either mentioned this puzzling phenomenon, or else unwittingly gave evidence of its existence. Furthermore, rough calculations from the dilatation measurements of Kempf and Hopkins[11] with ageing aluminium–copper alloys gave a fortuitously close agreement with the measured volume fraction of precipitate observed at Battelle. There appears to be a well documented case for the existence of anomalously high amounts of precipitate when it appears as small particles.

Therefore, on the basis of the five possible sources of error listed by the authors on page 158, it is questioned whether they are justified in assuming that their results were wrong, and whether the observed particle frequencies should have been shifted to the next lower size-group.

Aside from this point, however, and any concomitant effects occasioned by their assumption, it is believed that this paper represents a substantial achievement in quantitative metallography, in addition to its unquestioned value in establishing the details of the fourth stage of tempering.

AUTHORS' WRITTEN REPLIES

Dr. **Steven** wrote: We are grateful to Mr. Meyerson and Mr. Rosenberg for their interesting contribution, and are pleased to note the excellent agreement between their experimentally determined M_s temperatures and the corresponding values calculated from our formula.

The majority of the steels used to derive this formula had 'as-quenched' grain sizes of 5–8 on the A.S.T.M. scale, and we were unable to detect an effect of grain size within this range. We would certainly agree, however, that the possible effect of grain size deserves close study, and if the effect is significant a factor should be included in the equation.

The selected group of steels for which M_s–M_f ranges were determined had grain sizes between 4 and 8 on the A.S.T.M. scale, and within this range no effect of grain size on rate of martensite formation could be detected. Again, however, it is possible that the range of grain sizes covered was inadequate to reveal the effect of this variable.

An X-ray method capable of detecting 1–2% of austenite, and a magnetic method capable of detecting ½%, were used to examine the samples employed to determine the M_f temperatures. Accordingly, it is unlikely that appreciable amounts of austenite were present in the steels at the M_f temperatures quoted. We do not have sufficient information to make any firm suggestions to account for the discrepancies between the results obtained by Messrs. Meyerson and Rosenberg for M_f temperatures and those observed by us.

We have noted, however, that abnormal martensite formation ranges can be recorded from the microscopic examination of samples which are banded or segregated to an appreciable extent. The zones of low hardenability can result in high M_s temperature values and slow initial rates of martensite formation, and likewise abnormally low M_f temperatures can be recorded from areas high in carbon and alloy content. For this reason, we consider that microscopic examination should always be used to supplement the X-ray and magnetic methods of determining martensite formation in steels.

Mr. **A. G. Haynes** wrote: We have compared our experimentally determined martensite and bainite formation temperatures with values derived from chemical composition using the modified alloy factors suggested by Dr. Jones.

The effects of alloying elements on the M_s temperature are small in comparison with those of carbon, and therefore it was not surprising to find that the use of the modified factors did not seriously affect the accuracy of the M_s formula.

On the contrary, however, alloying elements have a more marked influence on bainite formation, and calculations using the modified composition factors showed poorer agreement with the experimentally determined values than was obtained using the original factors. There was a tendency for the calculated values obtained from the modified factors to be lower than the experimentally determined bainite formation temperatures. The most marked discrepancies were associated with steels of higher nickel content. Only 70% of the values derived from the modified factors were within ± 20–25° C of the experimentally determined bainite formation temperatures, compared with 95% of the values calculated using the original formula.

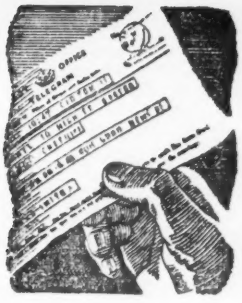
Dr. **Nutting** wrote: We should like to thank Dr. E. E. Underwood for his kind remarks on the value of our paper. We also have been puzzled by the anomalously high values of the observed volume fraction of the carbides. If the observed values are accepted then to account for them we must assume that the iron carbide is not of stoichiometric composition, but may contain excess iron. This is not an unreasonable assumption as there is considerable evidence to show that cementite extracted from high-carbon steels and cast irons after treatment at temperatures just above A_1 (when the cementite is in equilibrium with austenite) may contain excess iron, the amount of which decreases as the temperature is increased further. However, if we attempt to explain the results obtained in the present investigation by assuming non-stoichiometry of the cementite, the amount of excess iron required becomes very large and would correspond in the worst case to a composition of cementite of Fe_8C rather than Fe_3C. This we feel is much higher than would be expected, and therefore we think that errors in the sizing of the particles account for the abnormally high volume fractions of the precipitate.

REFERENCES

1. H. H. Burton and T. F. Russell: *J. Iron Steel Inst.*, 1938, vol. 138, No. II, pp. 57P–74P.
2. M. R. Meyerson and S. J. Rosenberg: *Trans. Amer. Soc. Metals*, 1954, vol. 46, p. 1225.
3. M. R. Meyerson and S. J. Rosenberg: *J. Res. Nat. Bur. Stand.*, 1955, vol. 55, No. 3, p. 177.
4. E. E. Underwood, L. L. Marsh, and G. K. Manning: "Creep of Aluminium–Copper Alloys during Age-hardening," Summary Report to N.A.C.A., Jan. 1956, Battelle Memorial Institute, Columbus, Ohio, U.S.A.
5. A. Guinier: *Z. Elektrochem*, 1952, vol. 56, p. 468.
6. J. M. Silcock, T. J. Heal, and H. K. Hardy: *J. Inst. Metals*, 1953–4, vol. 82, pp. 239–248.
7. I. J. Polmear and H. K. Hardy: *Ibid.*, 1952–3, vol. 81, pp. 427–431.
8. R. B. Shaw, L. A. Shepard, C. D. Starr, and J. E. Dorn: *Trans. Amer. Soc. Metals*, 1953, vol. 45, p. 255.
9. A. Phillips and R. M. Brick: *Metals and Alloys*, 1934, vol. 5, p. 204.
10. C. S. Roberts: *Trans. Amer. Inst. Min. Met. Eng.*, 1956, vol. 206, pp. 146 and 1410.
11. L. W. Kempf and H. L. Hopkins: *Ibid.*, 1936, vol. 122, pp. 266–281.

N E W S

Announcements and News of Science and Industry



IRON AND STEEL INSTITUTE

Autumn Meeting, 1957

The Autumn General Meeting of the Institute is being held in London on Tuesday, **24th September.** It will be followed by the Engineers Group Meeting at Church House, Westminster, on 25th and 26th September, the subject of which is "Air Pollution in the Iron and Steel Industry." Arrangements will be made for those taking part to meet on the evening of 25th September at an informal buffet supper.

Annual General Meeting, 1958

The Eighty-ninth Annual General Meeting will be held in London on Wednesday and Thursday, **7th and 8th May,** 1958. The Dinner for Members will be held at Grosvenor House, Park Lane, W.1, on the evening of 7th May.

New Publication

The Library and Information Department of The Iron and Steel Institute has recently produced No. 21 in the Institute's Bibliographical series, on "The Continuous Casting of Steel." It contains abstracts of the papers on this subject which have appeared since 1933.

Indexes have been prepared to the authors of papers, to the numerous processes and to the names of firms which have developed these processes. The Bibliography is obtainable from the Institute at 25*s*. (15*s*. to Members).

NEWS OF MEMBERS

Mr. **J. Cartwright** has been appointed a Director of Taylor Bros. and Co., Ltd.

Mr. **R. L. Fannon** has joined the Air Reduction Sales Company, New York.

Lord **Dudley Gordon** has been appointed a Member of the Clean Air Council.

Mr. **R. Haynes** has been appointed Director of Research of the Coil Spring Federation Research Organization.

Mr. **J. F. B. Jackson** has joined the Board of P.I. Castings (Altrincham) Ltd.

Mr. **F. P. Jansen** is now with the Empress Nickel Mine, Gatooma, Southern Rhodesia.

Mr. **M. K. Madhekar** has joined the Atomic Energy Establishment of the Government of India, Bombay, as a Junior Research Officer.

Mr. **P. W. Smith** is now with the Chemistry Department, University College, London.

Mr. **F. M. Stearn** has been appointed Assistant Works Manager of the Birmingham Works of Henry Wiggin and Co., Ltd.

Professor **M. W. Thring** has been appointed a Member of the Clean Air Council.

Mr. **H. H. Utley** is now Director and General Manager of the Davy and United Roll Foundry Ltd.

Mr. **K. G. Wood** is now Lecturer in Metallurgy at the College of Technology, Art and Commerce, Oxford.

Obituary

Dr. **William Norman Hindley** (*elected* 1945), of Petts Wood, Kent, on 13th April, 1957.

Mr. **Clarence David King** (*elected* 1931), of Pittsburgh, Pa., U.S.A., on 24th March, 1957.

Mr. **Edmond Jule Rang,** M.SC. (*elected* 1951), of North Shields, on 12th April, 1957.

CONTRIBUTOR TO THE JOURNAL

Arthur E. Powers—Metallurgical engineer for the Large Steam Turbine-Generator Department, General Electric Company, Schenectady, New York, U.S.A.

Dr. Powers obtained the degrees of B.S. in Metallurgical Engineering from Purdue University in 1942 and Ph.D. in Metallurgical Engineering from Lehigh University in 1951. He was employed by the Allegheny Ludlum Steel Corporation from June, 1942, to June, 1944, to do development work on armour plate and stainless steel. Since February, 1951, he has been employed by the Large Steam Turbine-Generator Department of the General Electric Company in Schenectady, New York.,

POWDER METALLURGY JOINT GROUP

The Councils of The Iron and Steel Institute and of The Institute of Metals have formed a Powder Metallurgy Joint Group, the objects of which will be to study the science, technology, and practice of powder metallurgy. Membership of the Joint Group will be restricted to Members of the two Institutes, though its meetings will be open to non-members.

The Inaugural Meeting of the Joint Group will be held at Church House, Westminster, on Wednesday, 4th December, 1957, from 10.30 A.M. to 4.45 P.M. An earlier meeting was not thought to be desirable, since a number of other meetings on the subject had already been arranged elsewhere during the year.

The programme of the Inaugural Meeting begins with an introductory statement of the Joint Group's aims and objects, followed by a lecture by Dr. Ivor Jenkins on "Recent Developments in Powder Metallurgy." A number of short papers on developments in the production and quality of metal powders will be presented before lunch, and the afternoon session will be devoted to a discussion on these papers.

Further meetings of the Joint Group are being planned as follows: March, 1958, all-day informal discussion on "Developments in the Practice of Compacting and Sintering"; autumn, 1958, all-day discussion on "The Powder Metallurgy of Ceramic-Metal Materials."

The activities of the group are being administered by a Powder Metallurgy Joint Committee, with members from both Institutes. Lieut.-Col. S. C. Guillan has agreed to act as Secretary, and further particulars may be obtained from him at 17 Belgrave Square, London, S.W.1.

BRITISH NUCLEAR ENERGY CONFERENCE

Binding of Journal

Binding facilities for Volume I of the *Journal of the British Nuclear Energy Conference*, comprising the January, July, and October, 1956, numbers, are available at the following charges, including postage:

Binding case only	12*s.* 6*d.* net.
Supplying case *and* binding	25*s.* 0*d.* net.

Subscribers should send orders for binding cases, or their copies of the *Journal* and index, enclosing the appropriate remittance, to William Clowes and Sons Ltd. (Publishing Department), Little New Street, E.C.4.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

10th Junior Blast Furnace Conference

The 10th Junior Blast Furnace Conference, held at Harrogate on 7th and 8th May, 1957, was attended by 90 members. The Chair was taken by Mr. E. M. Summers, and during the sessions the proceedings were under the guidance of two Vice-Chairmen, Mr. G. D. Venables and Mr. C. Oliver, the latter deputizing for Mr. R. Wilson, who was unable to attend.

Following an introductory statement, the Chairman presented a paper outlining the future requirements of the industry. He enlarged on ways by which this could be achieved, including burden preparation (particularly by sintering), improvement in coke quality, oxygen enrichment, and high top pressure.

The second part of the first session was this year devoted to the discussion groups. A summary of the discussion by each group was presented in the first part of the fourth session, when all members of the conference had an opportunity to comment on subjects of groups other than their own.

In the second session three papers on the improvement of lining life were presented. The first, concerning the actual refractory material itself, was given by Mr. H. M. Richardson, and described some recent work done on improving refractories. Mr. G. D. Venables gave the second paper, on a U.S. method of "Continuous Drying Out and Blowing In" used at the Steel Company of Wales Ltd. The last paper, by Mr. R. Wilson, discussed the practical advantages and disadvantages of cooling methods in different parts of the furnace.

Mr. R. Graham gave a paper in the third session on front side practice. He described standard practices as used at the Cargo Fleet Works of the South Durham Steel and Iron Co., Ltd.; the importance of good taphole clay was especially mentioned.

In the second part of the fourth session two papers by members of the Ironmaking Divisional staff were presented describing current research work. Mr. D. F. Ball described disc pelletizing, particularly in relation to its application to materials before sintering. Dr. B. G. Baldwin reviewed methods of measuring viscosity and liqudus temperatures of blast-furnace slags.

Each session provided for a general discussion, the main points of which were summarized by the Chairman in his closing statement to the conference.

Corrosion Exhibition

The Corrosion Section held an exhibition at the Battersea Laboratories from 28th to 30th May, which was seen by a large number of visitors. The object of the exhibition was to enable those especially concerned with corrosion problems to see something of the work of the Section. On display were a wide range of instruments and processes used for assessing the corrosion on samples exposed at a number of sites in the U.K. and abroad. These included the Sulphur Dioxide C.R.L. Test Apparatus for testing protective coatings, a rotor apparatus for studying the effects of corrosion inhibition by sodium silicate, and automatic equipment for stress-corrosion tests on stainless steel. Of particular interest was the display of the methods used for recording and tabulating data obtained in laboratory and field tests, including a punched-card system. The work of the Section has been largely concerned with heavy structural plain carbon and low-alloy steels; this has covered all aspects of the corrosion of these materials in various atmospheres and its prevention by surface preparation and protection with paint and metal coatings.

B.I.S.R.A. Performance Recorder

Recently developed by B.I.S.R.A. is a device for analysing the performance of machines, known as CROWD (Central Recording of Works Data). CROWD records the length of time the machine is engaged on any particular job or order, the amount of idle time, and the type and duration of any fault. This information is automatically collated at a central point for any number of machines and is delivered at the end of each shift in the form of standard punched cards.

The equipment has been installed by Guest, Keen and Nettlefolds Ltd., and has been in operation for some time, analysing 18 different operations. A short film has been produced and will be on show at the Engineering, Marine, Welding and Nuclear Energy Exhibition from 29th August to 12th September, 1957.

AFFILIATED LOCAL SOCIETIES

Leeds Metallurgical Society

The Officers and Members of Committee of the Leeds Metallurgical Society for the 1957–1958 session are as follows:

President
P. A. Green

Vice-President (1*st*)	*Vice-President* (2*nd*)
K. Hill	W. L. Bolton
Honorary Secretary	*Honorary Treasurer*
Dr. P. Feltham	A. Lenton

Committee
W. E. Creswick, E. W. Dewhirst, R. Mercer, Dr. E. Simister, P. G. Stone, L. H. Wadsworth, Dr. N. J. Petch (*permanent*)

Past-Presidents
A. Lenton, C. Breckon, C. Burrell

JERNKONTORET

Award of Gold Medal

The Gold Medal of Jernkontoret has been awarded to Professor Count Bo Kalling, in recognition of his contributions in different fields during more than forty years in the Swedish iron and steel industry. These have included early work on stainless steel, the development of sponge-iron methods, and studies of steelmaking processes. Of especial importance was his work as

Research Director of Stora Koppabergs Bergslags AB, when Professor Kalling carried out important studies on desulphurization and developed the Kaldo process for refining phosphorous pig iron in a rotating furnace with the aid of oxygen.

The Medal, which was founded in 1822, has been awarded in gold only six times before: to F. von Schéele (1832), J. P. Morell (1844), G. Ekman (1868), J. A. Brinell (1914), G. Jansson (1921), and C. Wahlund (1940). The recipients have all been men who have made exceptional contributions to the advancement of the Swedish iron and steel industry.

Director of Research

Mr. Sven Fornander resigned his position as Director of Research of Jernkontoret on 30th June to become Technical Director of Surahammar Bruks AB. His successor is Mr. Ulf Notini, formerly Chief Engineer at Domnarfvets Jernverks AB.

EDUCATION

Society of Chemical Industry Scholarship

The John Gray Jubilee Scholarship of £150 is tenable for one year at any approved University or Technical College. Candidates who may be of either sex, should be graduates in chemistry whose intention it is to enter industry, but those awaiting the result of their final degree examination may apply. Other qualifications being equal, preference will be given to the son of a member of the Society of ten or more years standing.

Applications must be made before 1st September, 1957, to the General Secretary, Society of Chemical Industry, 14 Belgrave Square, London, S.W.1, accompanied by a brief record of the candidate's school and university training, present forms of recreation, and the occupation of his or her parents.

Copies of testimonials from school-master and professor or tutor should be sent with the application, and the University or College at which the scholarship would be worked out should be stated.

NEWS OF SCIENCE AND INDUSTRY

New Director for B.W.R.A.

Dr. Richard Weck took up his duties as Director of Research of the British Welding Research Association on 17th April; he succeeds Dr. H. G. Taylor, who is now Director of the Electrical Research Association.

Dr. Weck graduated from the University of Prague in 1936 and came to England in 1938. After four years with the Electric Furnace Co., Ltd., and Messrs. Campbell and Gifford, he was appointed to the staff of the Welding Research Council. While with the Council he edited the well known Institute of Welding Handbook on Structural Steelwork. He was later seconded to the staff of Professor J. F. Baker at the University of Cambridge Engineering Department. Dr. Weck joined the B.W.R.A. in 1947, and was responsible for the development of high-speed methods for testing large welded structures. In 1951 Dr. Weck was appointed a lecturer in the Department of Engineering at Cambridge University, where he was charged with the special task of planning a post-graduate course for engineers; these courses have now been in operation for six years and have proved a great success.

National Anti-Corrosion Week

In an effort to reduce the immense bill for corrosion losses which industry faces every year, a National Anti-Corrosion Week is being organized from 14th to 19th October, 1957. During this period a new impetus will be given to the use of anti-corrosion products and services, and new information on corrosion and its prevention will be disseminated. A two-day convention on 15th and 16th October at Central Hall, Westminster, will be attended by delegates from all over the world. Simultaneously, at the Royal Horticultural Society's Old Hall there will be a three-day Corrosion Exhibition from 15th to 17th October, the first full-scale exhibition of anti-corrosion products ever to be held in the U.K.

The Convention and Exhibition are being organized by the publishers of the magazine *Corrosion Technology*; further information may be obtained from the Organizer, Stratford House, 9 Eden Street, London, N.W.1.

Corrigenda

Mr. T. Henry Turner wishes to point out that in the Discussion at the Corrosion Meeting (*J. Iron Steel Inst.*, 1957, vol. 186, May, p. 94) he said that the Atmospheric Corrodibility Index was put forward by the S.C.I. Corrosion Group; in fact, the index was discussed many times by the Atmospheric Corrosion Sub-Committee of B.I.S.R.A.

In the paper "Specific Heat and Resistivity of Mild Steel," by Dr. P. R. Pallister (*J. Iron Steel Inst.*, 1957, vol. 185, Apr., pp. 474–482), the fifth line of the right-hand column of p. 482 should read "required condition, the Ae_3 point for this steel."

DIARY

23rd June–3rd July—German Welding Society (D.V.S.)—Welding and Cutting Exhibition—Essen.

30th June–3rd July—Institution of Production Engineers—Conference on Automatic Production—Harrogate.

1st–6th July—International Institute of Welding—Annual Assembly—Essen.

2nd July—Fulmer Research Institute—Open Day—Stoke Poges.

3rd–6th July—Commission on the Physics of Solids (IUPAP) and National Science Foundation—Conference on Current Problems in Crystal Physics—Cambridge, Mass., U.S.A.

9th–20th July—Cambridge University—Summer School on the Use of Electrons in the Examination of Metals—Cambridge.

10th–12th July—Joint Conference on Thermodynamics and Transport Properties of Fluids—London.

10th–20th July—4th Plastics Exhibition and Convention—Olympia, London.

10th–17th July—International Union of Crystallography—4th General Assembly and International Congress—Montreal.

18th–24th July—16th International Congress of Pure and Applied Chemistry (IUPAC) and 19th Conference of International Union of Pure and Applied Chemistry—Paris.

TRANSLATION SERVICE

(The previous announcement was made in the June, 1957, issue of the Journal, p. 270).

Translation Available

No. 529 (German). W. Lueg and H. G. Müller: "The Load on a Three-high Finishing Stand and on Its Drive in Hot-rolling Sheet Bars and Billets." (*Stahl und Eisen*, 1956, vol. 76, Nov. 1, pp. 1457–1463). (Translation made available through the courtesy of Mr. R. Sewell and The United Steel Companies, Ltd.)

Translations in Course of Preparation

(German). V. Seul and J. Billigmann: "Design, Mode of Operation, and Operating Results of a Modern Wide Strip Annealing Plant." (*Stahl und Eisen*, 1957, vol. 77, Mar. 21, pp. 309–323). (Translation prepared by Miss V. Moore and made available through the courtesy of Richard Thomas and Baldwins, Ltd.)

(German). F. Fischer, M. Nacker, and V. Seul: "The Influence of Various Temper-rolling Conditions and of Ageing on the Yield Point of Deep-drawing Strip Steels." (*Stahl und Eisen*, 1957, vol. 77, Mar. 21, pp. 340–346). (Translation prepared by Mr. K. Metzer and made available through the courtesy of Richard Thomas and Baldwins, Ltd.).

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

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MINERAL RESOURCES

The Strategic Position of Iron Ore in the Economy of the Atlantic Basin Nations. W. H. Voskuil. (*Illinois Engineer*, 1956, 3–8, reprint; *Illinois State Geological Survey Reprint Series*, 1956—U). A survey of sources of supply outside the industrial nations with an account of transport difficulties is presented.

The Application of Layer-by-layer Thermography to the Study of the Genesis of Iron Ores. V. T. Kaurkovskiĭ. (*Trans. 1st Congress Thermography, Akad. Nauk S.S.S.R.*, 1955, 211–218). [In Russian]. A sample of differentially oxidized siderite ore, cut layer-by-layer, provided material for a combined thermographic, chemical, and densiometric study. In this way the mineral composition of each genetic stage was determined and the process of formation of the oxidized ore elucidated.—S. I. T.

On the Geological Position and Facies of the Tula Iron-ore Deposits. B. P. Epifanov. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **108**, (2), 305–308). [In Russian]. The deposits of the brown iron ore of Tula district occur among the strata of Lower Carboniferous age at their junction with the overlying Cretaceous rocks. The study of grain-size and minerals of this ore confirms that it is of a true syngenetic origin and was formed in a marine-lagunar environment.—S. I. T.

Concretional Formation of Productive Deposits in the Western Part of the Donetz Basin. P. V. Zaritskii. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **108**, (2), 329–332). [In Russian]. This is a field and a chemical study of iron carbonate concretions occurring in the productive suite of the Middle Carboniferous strata of the Donetz basin. Besides siderite these concretions contain pyrites, kaolinite, and other minerals. Sulphate and silica concretions are also present.

Pyrite Deposits at Horseshoe Bay, Latouche Island, Alaska. F. A. Stejer. (*U.S. Geol. Survey Bull.* 1024-E, 1956, 107–122).

Iron and Manganese Ores of Brazil. O. H. Odman. (*Eng. Min. e Met.*, 1956, **23**, May, 219–221). [In English]. One figure for the iron ore reserves of Brazil is given as 38,250 million tons, the deposits of the Minas Gerais comprising an appreciable part of this total. At least 63 million tons of ore containing over 42% manganese exist in three principal deposits and these are being worked in conjunction with U.S.A. capital. The geological nature of these ore beds is described.—P. S.

Geology and Ore Deposits of the Atacocha District Departamento de Pasco, Peru. R. F. Johnson, R. W. Lewis Jun., and G. Abele C. (*U.S. Geol. Survey Bull.*, 975-E, 1955, 337–388). Pyrites and other iron minerals occur.

Egyptian Mineral Resources. M. E. El-Din El-Zoghby. (*Rev. Ind. Min.*, 1955, **36**, Oct. 1, 1072–1082). Iron deposits are reviewed.

Iron and Steel Industries of the World. I. Ore Reserves and Production. (*Financial Times Survey*, [1957], 32).

Present State and Anticipated Development of Iron Ore Supply. E. Plotzki. (*Stahl u. Eisen*, 1956, **76**, Dec. 27, 1728–1734). The world iron and steel production has increased from 115 million metric tons in 1945 to 268 million tons in 1955. Further increases are to be expected in the future. The author analyses the world sources of iron ore supply, the possibility of increasing the output of the various districts and discusses in detail new sources, their occurrence, position, quantity, type of ore and percentage, mining aspects, transport and capital outlay required.—T. G.

ORES—MINING AND TREATMENT

Algoma Ore Properties Ltd. (*Canad. Min. J.*, 1956, **77**, Nov., 76–130). A comprehensive account is presented of the geology, mining operations, crushing and hoisting, of the sink-float plant with magnetic separation, conveying, sintering plant and practice, and assaying; and of service and engineering and other departments.

Increasing Importance of Brazil as One of Britain's Suppliers of Iron Ore. (*Brazilian Bulletin*, 1956–1957, **8**, Dec.-Jan., 25). Statistics are tabulated.

One Hundred Million Dollars Forthcoming for Iron-Ore Mining. (*Brazilian Bulletin*, 1956–1957, **8**, Dec.-Jan., 24–25). An agreement between the Companhia Vale do Rio Doce and an American group is reported.

The Initiation of Explosive Charges. T. W. Edmond. (*Mine Quarry Eng.*, 1957, **23**, Mar., 118–123). Ironstone operations in the Corby area are reviewed with reference to developments in horizontal blasting. The reduction of ground vibration is particularly considered.

Ocean Iron Ore Carriers—Design Considerations. J. Lenaghan. (*Institution of Naval Architects*, 1957, preprint, pp. 9).

On the Hydration of Iron Oxides and their Transformation into Hydroxides; (Illustrated by Data from Krivoi Rog). Yu. Yu. Yurk. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **109**,

(1), 144–147). [In Russian]. Hydrated hematite, martite, and pyrites are common among the iron ores of Krivoi Rog, and the author suggests that hydration was promoted by the sulphates present in the circulating solutions.—S. I. T.

Thermographic Characters of Siderites. V. I. Kauzkovskii. (*Trans. 1st Congr. Thermography, Akad. Nauk S.S.S.R.*, 1955, 205–210). [In Russian]. This is a thermographic study of siderite ore heated in a normal and in a limited supply of air. The step-line nature of the thermal dissociation curves is explained to be due to the polycrystalline structure of the ore.—S. I. T.

Laboratory Studies on the Beneficiation of some Ferruginous Manganese Ores of India for the Production of Ferromanganese. P. I. A. Narayanan and G. V. Subramanya. (*Bull. Inst. Min. Met.*, 1956, **66**, Dec., 49–68). The magnetizing roast process is developed.

Ore Concentration by Wet Spiral. G. A. Clayton. (*Brit. Steelmaker*, 1956, **22**, May, 132–135). An account of iron ore treatment as carried on in the Lake Superior district and other locations with an outline of the process and plant and tables of screen analyses for the Humphreys Spiral concentrator.

Modern Methods of Ore Preparation. L. Frank. (*Metall*, 1957, **11**, Jan., 10–17). The modern flotation method of ore and mineral preparation is described in all its stages, reference being made to installations in operation.—J. G. W.

Fluidized Solids Technique. Magnetic Conversion of Iron Ores. R. J. Priestley. (*Ind. Eng. Chem.*, 1957, **49**, Jan., 62–64). A brief description of a process for the conversion of haematite in low-grade ores to magnetite, and subsequent magnetic concentration.

Treatment of Low-grade Ores in Czechoslovakia. O. Mižik. (*Czech. Heavy Ind.*, 1956, (10), 35–44). Iron and copper ores are dealt with, and flotation plant and crushing shops are described and shown in plans.

On the Magnetic Roasting of Iron Ores. A. Kondo et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 914–915). [In Japanese]. Results are given for hydrogen reduction for varying times at 450° C of hematite, magnetite, and limonite ores.—K. E. J.

The Oxygen Flash Smelting Process of the International Nickel Company. (*Trans. Canad. Inst. Min. Met.*, 1955, **58**, 158–166). The roasting of sulphides of lead, iron, copper etc. is described.

Fluidized-Bed Roasting of Pyrites. M. Watanabe and A. Kigoshi. (*Sci. Rep. Res. Inst. Tôkohu Univ.*, 1956, **8A**, Dec., 511–531). Sulphatizing roasting of Co, Cu, and Zn-bearing FeS_2 was studied. A reactor with a capacity of 5 kg ore per day was used and 600° C was found to be the most suitable temperature. Water extracted 83–85% and dilute acid 90–95% of Co and Cu, Fe remaining insoluble. Magnetic separation of the residue was possible, the non-magnetic part concentrating Co, Cu and S which could be recovered.

Sintering Test of Pyrites Cinder. A. Chida et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 906–907). [In Japanese]. Studies on two types of pyrites cinder show the effects of increasing coke content between 6 and 10% in improving sinter strength and yield.—K. E. J.

Sintering Test of Magnetite and Hematite. T. Yazuka et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 908). [In Japanese]. Changes during sintering of mixtures of different ores are followed from analyses of waste gas, the coke content being constant at 3%. Changes in waste gas composition are shown for variation in coke content between 2·5 and 6·5%.—K. E. J.

Theory and Practice of the Production of Self-fluxing Sinter for Blast Furnace Use. D. G. Khokhlov and V. Ya. Miller. (*Stal'*, 1955, **15**, (6), 488–497). The mechanism of the lime–iron oxide reaction and conditions for production of sinter from various ores is investigated. At moderate temperatures lime reacts with Fe_2O_3 to form relatively low-melting ferrites. Gas evolution increases porosity so that relatively large amounts of melt need to be formed and the product is somewhat brittle. Finally reducibility falls with fusibility and increased carbon content is to be avoided as it produces strong bonding and coarse structure.

Problems of Bloomery Plant Construction from the Viewpoint of the Technological Equipment. J. Mach. (*Czech. Heavy Ind.*, 1956, (5), 39–44). The use of iron-poor, highly acid, dust iron ores in a rotary sintering process is described and illustrated.

Study on the Permeability of Sinter Beds. M. Arai et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 915–916). [In Japanese]. The influence of moisture content between 0 and 26% on the permeability of the bed is shown for several ores, iron sand, coke, pyrites cinder and a raw mix. The influence of additions such as scale, cinder, and slag on the permeability of the raw mix, and the effects of moisture content on mixes containing 0–60% of return fines, are also described.—K. E. J.

On the Use of Pyrrhotite in Iron Ore Sintering. I. T. Yatsuka et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 918–919). [In Japanese]. Sinter yields and strengths, for coke amounts of 2·5–4·0%, are shown to increase as the pyrrhotite amount increases from 0 to 12%, and variations of SO_2 content in the waste gas are described.—K. E. J.

Agglomerating Fine Sized Ores with Low Temperature Coke. C. E. Lesher. (*J. Met.*, 1955, **7**, Oct., 1114–1118). Two processes are described. One with limited amounts of coke carbon (Orcarb process) and the other with low-temperature coke as binder. Continuous working in a rotating retort is described with 25–40% carbon or more.

FUEL—PREPARATION, PROPERTIES, AND USES

Interpretation of the Separation Curve and the Probability Chart in the Control of [Coal] Washeries. A. Terra. (*Rev. Ind. Min.*, 1955, **36**, June, 732–742).

General Results of Work on Coal Flotation and Scientific and Technical Outlooks on its Expansion. I. N. Plaksine. (*Rev. Ind. Min.*, 1955, **36**, June, 755–765).

Recent Developments in the Theory of the Possibilities of Washing and its Application to French Coals. P. Belugou and J. Daniel. (*Rev. Ind. Min.*, 1955, **36**, June, 695–707). Graphical and other methods of estimating washability are shown with examples.

Four Years' Balance of Washing in Dense Liquids. Conditions of Utilization. M. Bonduel. (*Rev. Ind. Min.*, 1955, **36**, June, 708–716). Coal washing with magnetite suspensions is reviewed.

Improvements in Mechanical Preparation in the Bassin du Nord and the Pas-de-Calais. A. Terra and A. Luscher. (*Rev. Ind. Min.*, 1955, **36**, June, 717–729). Coal preparation is reviewed in some detail.

Chemical Structure and Properties of Coal. XVII—A Mathematical Model of Coal Pyrolysis. H. A. G. Chermin and D. W. van Krevelen. (*Fuel*, 1957, **36**, Jan., 85–104). The consecutive reaction theory is used and an activation energy of pyrolysis of about 50 kcal/mole is derived.

Analyses of Ash from United States Coals. W. A. Selvig and F. H. Gibson. (*U.S. Bur. Mines, Bull.* 567, 1956, pp. 33). Analyses of coals and ashes and determinations of ash fusibility are tabulated.

Standardization of the Methods of Analysis of Coal and Coke. Determination of the Moisture Content of the 'Analysis' Sample. A. Crawford. (*Fuel*, 1957, **36**, Jan., 7–25). **Determination of Total Sulphur in Coal, II—The Strambi Bomb Combustion Method.** P. J. Jackson. (26–38). **Determination of Carbon in Coke by the Sheffield High Temperature Method.** H. C. Wilkinson. (39–42).

The Supply of Coal for Coke Manufacture. R. Lowe. (*Science and Art of Mining*, 1956, **67**, Dec. 22, 157). Sulphur in coal, especially pyritic sulphur, is discussed and its removal considered. The use of the Dutch State Mines cyclone washer for a coal with finely disseminated pyrites is mentioned.

Role of Hydrogen Bonds in the Briquetting of Lignite. M. S. Iyengar, D. N. Sibal, and A. Lahiri. (*Fuel*, 1957, **36**, Jan., 76–84).

Some Recent Developments in the Physics of Fuel Combustion. M. W. Thring. (*Brit. J. Appl. Phys.*, 1957, **8**, Mar., 89–97). The burning of oil droplets, in conditions such as exist in the O.H. furnace, is described and work with an aerodynamic model reported. Experiments on micro-mixing in jets are reported using a model of a magnetite suspension projected into water streams. Water models of coke oven hairpin flues and dust distribution studies from a "sticky dust" model were used, and heat transfer from flames, general questions of stability and combustion rate are considered.

Coke and By-Products in 1955. I. E. Madsen. (*Iron Steel Eng.*, 1956, **33**, Nov., 124–130). Statistics of production and use of oven and beehive coke are given.

On the Mechanism of Formation of Coke. P. A. Tesner. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **110**, (4), 620–622).

[In Russian]. This is the study of the second stage of coking, when semi-coke formed during the first stage is further polymerized with formation of a surface layer of carbon. Experiments on soot spheroids show that on treatment at 800° C in benzene vapour they developed a carbon surface layer 8–10 atoms thick. Soot deposited on the walls of the furnace is sometimes cemented by carbon into hard lumps. Experiments on carbon rods also showed the formation of a carbon surface layer.—S. I. T.

Studies in the Mechanism of Coke Formation: Part III—Plastic Properties of Washed Fractions and Blends of Coals and Their Coking Behaviour. S. R. Ghosh, N. N. Das Gupta, and A. Lahiri. (*J. Sci. Indust. Res.*, 1957, **16B**, Jan., 32–37). A modified Gieseler apparatus and retort were used. Correlation of fluidity and plastic temperature range with rank and coking was attempted without much success but with certain limitations coke quality can be predicted.

The Structure of Metallurgical Coke. A. Lermusiaux and E. Quinot. (*Chim. Ind.*, 1956, **76**, Dec., 1267–1275). An X-ray study is described. It is assumed that coke is made up of spherical particles electronically homogeneous of random orientation. The radii of the particles are calculated and they seem to be hollow when they correspond to C_{12} molecules made up of two rings with a spacing of 3·4 Å.

Metallurgical Coke. On a Particular Case of Adjustment of the Coking Properties of a Blend of Soft Coals with High Volatile Matter Contents. F. Pintado Fe and J. R. Garcia-Conde. (*Inst. Nac. Carbon Bol. Inf.*, 1956, **5**, Sept.-Oct., 199–208). [In Spanish]. A design for a blending plant to prepare blends for metallurgical coke from fines (1–10 mm) and flotation slimes (0–1 mm) of a high volatile-matter caking coal, a typical coking coal, and a low volatile-matter weakly-caking coal was required. Box tests indicated that the best results were obtained from a blend of these in the proportions 83%–7%–10% respectively, giving a Micum index of 81 compared with 63·5 for the high volatile coal alone. A simplified grinding process (for 130 t per h) is proposed, grinding to 3 mm except for the low volatile coal, which is ground to 1 mm, and 13% of the high volatile coal which is added directly as slimes. An even simpler grinding scheme is also proposed on grounds of economy: this eliminates most of the screening.—P. S.

On the Manufacture of Shaped Metallurgical Coke from Inferior Coal. III. S. Ida et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 910–912). [In Japanese]. Results are given from tests on Kokura (lignite), Takamatsu (non-caking), Onoura and Omine (weakly caking), and Ushibuka (anthracite) coals, for which analyses etc. are given. For the coals, the coke yield varied from 59·5 to 62%, and the calorific value of the gas from 4307 to 4644 kcal; for the anthracite the values were 86% and 3570 kcal, respectively.—K. E. J.

On the Control of Qualities of Coke by Measuring Weight of 1 Cubic Meter Volume. M. Serisawa. (*Tetsu to Hagane*, 1956, **42**, Sept., 912–913). [In Japanese].—K. E. J.

The Treatment of Water for Use in Coke Oven and By-Product Plants. F. Walsh. (*Gas World, Coking Section*, 1957, **50**, Mar. 2, 45–48).

Local and Interplant Gas Dispatching for Steel Plants. H. J. Rohm. (*Iron Steel Eng.*, 1956, **33**, Nov., 57–64). United States Steel Corporation organization and practice in the Chicago and Pittsburgh districts are described. Coke oven, blast-furnace, and natural gas are distributed and co-ordinated.

On the Carbon Deposition in Generating Propane Gas. S. Yamada et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 754–755). [In Japanese].—K. E. J.

AIR POLLUTION AND SMOKE

The Rise of a Hot Waste Gas Plume. C. H. Bosanquet. (*Inst. Fuel, Advance Copies*, 1957, pp. 7). An equation is developed on certain assumptions on upward momentum and rate of dilution giving the track of hot gas rising in a wind of any velocity.

Maximum Gas Concentration at Ground Level from Industrial Chimneys. A. C. Best. (*Inst. Fuel, Advance Copies*, 1957, pp. 5). It is shown that three expressions for plume height give similar values for concentration and distance from the chimney of the ground level maxima.

Evaluation and Interpretation of Records from the I.S.I. Automatic Smoke Sampler. W. C. L. Hemeon, G. F. Haines Jun., and H. M. Ide. (*Amer. Iron Steel Inst. Report and I.H.F. Information Circular No.* 6, 1953, May, pp. 17 + numerous plates and diagrams).

Monitor for Peak Combustion Efficiency Measures O_2 Content in Flue Gases. (*Blast Furn. Steel Plant*, 1957, **45**, Jan., 86–89). A new automatic system which measures the oxygen content of the exit gases and adjusts the air–fuel ratio to maintain optimum combustion conditions is described.

Measurement of Dust and Fumes in Stack Gases. I. Procedures for Stack Dust Sampling at One Point. II. Minimizing Errors due to Departure from Isokinetic Sampling. III. The Manifold Sampler—A New Technique. G. F. Haines Jun. and W. C. L. Hemeon. (*Amer. Iron Steel Inst. Report and I.H.F. Information Circulars No.* 5 *and No.* 9, March, 1953, 1954, pp. 29 + vii + numerous plates and diagrams; pp. 11 + plates and diagrams).

Sulphur in Cupola Stack Gases. F. M. Shaw. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1956, **6**, Dec., 444–454). The amount of sulphur oxides emitted by cupolas is much less than that emitted from typical solid fuel fired boilers burning fuel at comparable rates. A sulphur balance for cupola operation is drawn up and though the results are scattered, 40–70% of the coke sulphur is absorbed by the iron and slag, by far the greater proportion going into the metal. Decreasing the sulphur oxides leaving the cupola by means of spray type dust collectors is discussed.—B. G. B.

Problems of Dust Precipitation. E. Eichler. (*Technik*, 1956, **11**, Aug., 585–590). Suitabilities of various techniques of dust precipitation are examined in relation to the type of dust. The most important types of precipitator are described, with information on their performance. (18 references).—J. G. W.

Concepts and Terms in Testing Methods for the Quantitative Determination and Qualitative Study of Dust. J. Kistler. (*Technik*, 1956, **11**, Dec. 12, 845–847). Methods of sampling and instruments for the measurement of dust concentration are described and the theories underlying the behaviour of the carrier gas are briefly indicated.—J. G. W.

Measurement of Fine Dusts by Means of Conimetric Measuring Instruments. R. Roeber. (*Technik*, 1956, **11**, Aug., 580–584). Performance and application of various types of conimeter used in determining dust concentration are discussed, reference being made to the author's experience and investigations.—J. G. W.

Small Melting Shop Dust and Fume Control. C. W. Finkl. (*J. Met.*, 1956, **8**, Dec., 1658–1660). A description is given of the steps taken to meet the dust and fume problem in the two-furnace electric melting shop of A. Finkl and Sons, Chicago. They included the provision of air heaters to carry smoke up to the roof fans, and later the installation of furnace hoods and dust collectors. The effectiveness of the installations is assessed.—G. F.

Inflammability and Explosion. Risk of Industrial Dusts. H. Hanel. (*Technik*, 1956, **11**, Nov., 785–792). Inflammability and explosion risks of a wide range of dusts encountered in industry are analysed, and methods of control and prevention are discussed.—J. G. W.

TEMPERATURE MEASUREMENT AND CONTROL

Modern Pyrometry. L. Walter. (*Brit. Steelmaker*, 1956, **22**, May, 136–138; June, 164–166). An illustrated review of apparatus with circuit and control details.

An Improved Two-Colour Pyrometer and its Application. G. Naeser. (*Stahl u. Eisen*, 1956, **76**, July 26, 968–970). The principles and advantages of colour pyrometry are reviewed, and construction, calibration, and range of application is discussed. Among the subjects to which the author alludes are: the determination of the quality of iron and steel melts, the measurement of flame temperature and radiation, and the determination of the particle size of carbon black.

The Position of Electrical Measurement Technique, Particularly for the Measurement of Non-electrical Quantities. W. Hunsinger. (*Berg Hüttenmänn. Monatsh.*, 1956, **101**, Sept., 173–182). Temperature measurements in steel furnaces are discussed, and spectrographic determinations among many other topics.

The Error of Thermocouple Pyrometers used in the Furnaces of Steel Works. M. Jindai et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 751–752). [In Japanese]. Errors in the temperature range 200–1000° C are considered.—K. E. J.

Measurement of Open Hearth Bath Temperature. Y. Mitarashi et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 740–742). [In Japanese]. Experiences are described for temperature measurement systems on 60-ton and 120-ton stationary furnaces and tilting furnaces of capacities between 100 and 150 tons. Over 98% of good measurements were made, and the failures of thermocouples are analysed. Standard deviations of bath temperatures for a six-month period are quoted.

REFRACTORY MATERIALS

Refractory Materials at the GIFA Exhibition. F. Roll. (*Giesserei*, 1956, **43**, Dec. 20, 849–851). The exhibits of refractory materials shown at the GIFA exhibition are described. A review of the production of refractory materials of use in the foundry is given in tabular form. Linings for various types of furnaces are similarly tabulated. A graph is given of the melting temperatures of Al_2O_3—SiO_2 mixtures, showing the useful region for the manufacture of refractories. Acid, basic, neutral, and specially produced refractories are described, including both those occurring naturally and those made by man.—R. J. W.

From Palaeolithic Man to Densyl Bricks. (*Brit. Steelmaker*, 1956, **22**, May, 128–130). A description of General Refractories Ltd. new works at Austerfield, using Cretaceous flint as raw material.

Processing of Certain North American Kyanite Concentrates into Volume-Stable, Dense and Highly Refractory Aggregate. V. D. Svikis and J. G. Phillips. (*Amer. Ceram. Soc. Bull.*, 1956, **35**, Aug., 305–308). Phosphoric acid and aluminium phosphate may be added without reducing refractoriness.

Hot Face Insulation Refractories from Bladed Kyanite: Part II.—Factors Influencing the Production of Kyanite Insulation Refractories. H. P. S. Murthy and Rabindar Singh. (*J. Sci. Indust. Res.*, 1957, **16B**, Jan., 38–42). Porous compositions are produced by incorporating sawdust, foundry or petroleum coke. Effects of different combustible materials, different proportions, and different temperatures are investigated. In highly porous products a relation between porosity and refractoriness under load is observed.

Norton's New Electric Furnace Plant for Producing High Temperature Materials. (*Indust. Heating*, 1956, **23**, Dec., 2662, 2664, 2666–2667, 2706). Boron carbide, zirconia, magnesia, and alumina will be fused.

A High Temperature Propane–Oxygen Furnace. R. C. Phoenix, D. R. Robinson, and E. Ruh. (*Amer. Ceram. Soc. Bull.*, 1956, **35**, Aug., 303–304). A furnace for firing samples of refractories above 3500° F is described. Zirconia refractories were used.

Incorporation Experiments on Synthetic Mullite. Part I. G. Gelsdorf and H.-E. Schwiete. (*Arch. Eisenhüttenwesen*, 1956, **27**, Dec., 807–811). X-Ray investigations have shown that 6% Al_2O_3, 3% Fe_2O_3, and 1·5% TiO_2 can be incorporated in the mullite lattice at 1450°, but only iron and titanium oxides effected an increase in lattice spacing.—L. J. L.

Treatment Eliminates Silica Dust. (*Steel*, 1956, **139**, Sept. 3, 86). The application of "Orzan A" solution (ammonium lignosulphonate) to silica bricks, eliminates dust during handling.—D. L. C. P.

Available Quality and Quantity of Water for the Ceramic Industries. W. H. Durum. (*Amer. Ceram. Soc. Bull.*, 1956, **35**, Nov., 417–421). **Water as a Ceramic Raw Material.** G. W. Phelps and S. G. Maguire Jun. (422–426). **Effect of Water in Enamel and Glaze Operations.** R. F. Patrick and J. E. Marquis. (427–429). **Ceramic Process Water Conditioning by Ion Exchange.** W. E. Coombs Jun. (430–432).

Testing of Refractory Products for Refractoriness-Under-Load. C. T. S./P. R. A. (*Radex Rundschau*, 1956, (6), 263–271). A technical commission of European manufacturers formed in 1953 reports its co-operative investigation of the refractoriness-under-load test with regard to silica, siliceous fireclay, and 42/44% Al_2O_3 bricks. A statistical examination according to laboratories and products shows that (1) for silica bricks—the use of either a 34 or 50 mm test-piece with a temp. rise of 4° C per min gives equally good reproducibility but by using a test-piece of 50 mm and a temp. rise of 8° C per min entirely different results are obtained; (2) for siliceous fireclay bricks—the differences for different test conditions are not marked; the difference between laboratories appears greater than between different testing methods; (3) for 42/44% Al_2O_3—there were insufficient results to determine whether differences were significant. Examination without reference to laboratories to determine role of sample size, rate of temperature rise, and product shows that (*a*) for silica bricks the variance ratios are not significant, (*b*) for siliceous fireclay and 42/44% Al_2O_3 bricks the variance ratios are significant between the initial softening point and the other points (0·6% and 20% deformation). Proposals for the construction of testing apparatus and for an international standard testing procedure are appended.

Remarks on the Structure of Dolomite. M. Amblard. (*Centre Doc. Sidér. Circ. Inf. Tech.*, 1956, **13**, (11), 2227–2228). The influence of the chemical and physical structure of dolomite on its suitability for use in basic converters is briefly discussed.—B. G. B.

A Note on the Evaluation of the Thermal Diffusivity of Refractory Materials in a Non-Steady State. J. Robredo Olave. (*Rev. Cienca Apl.*, 1956, **10**, July-Aug., 334–337). [In Spanish]. A general equation is derived which relates the temperature $\theta(n+1)\Delta t$ at the instant $(n+1)$. Δt seconds with the temperature $\theta_n\Delta t$ at the previous instant and includes the thermal diffusivity of the refractory. A simple experiment to measure this is described; it consists of a furnace with five thermocouples embedded at various levels within the material to be tested. Results for porous kaolinite bricks are given and discussed. Tests were made over the range 155–560° C, giving thermal diffusivities ranging from 0·00242 to 0·00386 $cm^2\ s^{-1}$. (14 references).—P. S.

An Unusual Form of Mullite. L. T. Kazyakin and O. M. Margulis. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **109**, (4), 821–823). [In Russian]. Mullite, in the form of isometric grains and short prisms, was found in fire bricks made of kaolinite and fired at 1450° C. Optical and X-ray data are given.—S. I. T.

Phase Equilibria in High-Alumina Part of the System CaO–MgO–Al_2O_3–SiO_2. R. C. De Vries and E. F. Osborn. (*J. Amer. Ceram. Soc.*, 1957, **40**, Jan., 6–15).

Strength Properties of Sintered Alumina in Relation to Porosity and Grain Size. I. B. Cutler. (*J. Amer. Ceram. Soc.*, 1957, **40**, Jan., 20–23). Rods sintered at temperatures above or below recrystallization temperature were examined. Minor decreases in strength resulted from increase in grain size or in void size.

Petrology of Fused Cast High Alumina Refractories. H. N. Baumann Jun. (*Amer. Ceram. Soc. Bull.*, 1956, **35**, Sept., 358–360).

Effect of Porosity on Physical Properties of Sintered Alumina. R. L. Coble and W. D. Kingery. (*J. Amer. Ceram. Soc.*, 1956, **39**, Nov., 377–385). Porosity was produced by including naphthalene in the slip. Expressions for effects on elasticity and strength are given.

Surface Energies of Solid Oxides and Carbides. D. T. Livey and P. Murray. (*J. Amer. Ceram. Soc.*, 1956, **39**, Nov., 363–372). FeO is included.

Initial Thermal Expansion Characteristics of Insulating Refractory Concretes. M. S. Crowley. (*Amer. Ceram. Soc. Bull.*, 1956, **35**, Dec., 465–468). Laboratory data are presented and correlated with composition and rate of heating. Furnace design is considered in the light of data of this kind.

Information on Pressure Cracking of Dry Press Brick. S. M. Phelps. (*Technical Bull. Refractories Institute*, 1957, Jan., pp. 7). Results of a questionnaire from 7 makers of refractories.

On Cristobalite and its Transformation into Tridymite. N. N. Sinel'nikov. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **110**, (4), 651–654). [In Russian]. On heating quartz in the presence of Na_2CO_3 it is transformed to cristobalite and at the same time cristobalite is transformed into tridymite. In the present paper a detailed X-ray, spectroscopic and optical study is made of the cristobalite–tridymite transformation and its products in relation to concentration of the mineralizer, temperature, and time.—S. I. T.

A Contribution to the Quartz-Cristobalite Conversion. II. The Effects of Temperature, Time, and Surface Area on the Conversion Characteristics of Boulders of Quartzite and Rock Crystal. H. A. Schwiete and H. Stollenwerk. (*Arch. Eisenhüttenwesen*, 1957, **28**, Jan., 17–30). The principles of quantitative X-ray analysis are outlined. The study of mixed samples of quartz, tridymite, and cristobalite is described. Results are reported of chemical investigations of the distribution of oxide impurities in the various particle size groups, and of X-ray investigations of the conversion characteristics of

quartzite and rock crystal as a function of temperature, time, grain size, and surface area.—L. J. L.

Contribution on Iron Oxide and Alkali Bursting of Refractory Bricks. F. Trojer. (*Radex-Rundschau*, 1956, June-July, 189–196). Microscopical examinations of the iron oxide bursting of chrome-magnesite bricks and the swelling of fireclay bricks using reflected and transmitted light are described. The results of slagging tests are also given. In chrome-magnesite bricks the iron oxide bursting is proportional to the degree of crushing and the mean grain size of the chrome ore used. In fireclay bricks the alkali bursting is conditioned by the alkali supply at 1200–1300° C and develops primarily from the formation of felspar and leucite.

Refractories in Cupola Practice. J. R. Park. (*Foundry Trade J.*, 1957, **102**, Feb. 7, 165–167). Lining with refractory bricks, rammed linings, and water-cooled cupolas are considered. Firebrick properties are discussed and rammed linings and patching materials are then dealt with, all in general terms. Basic and neutral linings are briefly mentioned.

Refractories Used in Cupola Practice. (*Bradley's Magazine*, 1956, Winter, 6–7). The repair of linings is discussed.

Basic Checkers Proved Economical on Replacement Comparison with Clay. C. C. Benton. (*J. Met.*, 1955, **7**, Oct., 1088–1089). Experience at Algoma Steel Corp. is described.

Zircon Ladle Linings in Basic Electric Furnace Practice. W. A. Koppi. (*J. Met.*, 1956, **8**, Dec., 1649–1650). Zircon ladle linings are in use in the basic electric shop at Lebanon Steel Foundry. The author gives brief details of the performance, maintenance, and economics, and indicates the resulting overall improvement in steel quality.—G. F.

High Alumina Ladle Linings. V. J. Howard. (*J. Met.*, 1956, **8**, Dec., 1646–1647). Teapot ladles at Oklahoma Steel Castings Co. are lined with high-alumina (80%) material. Its advantages and disadvantages are outlined, and particular attention is given to the correct ramming of the material.

Zircon Ladle Linings for Cleaner, Low Cost Metal. W. D. Emmett and V. E. Zang. (*J. Met.*, 1956, **8**, Dec., 1648–1649). A summary is given of the advantages and disadvantages of monolithic ladle linings of zirconite sand. The correct procedure to adopt in lining and firing the ladle is outlined.—G. F.

The Appraisal of Furnace Linings. E. Spetzler. (*Stahl u. Eisen*, 1956, **76**, Dec. 27, 1734–1740). This is a technical-economic account of the advantages of the use of chrome-magnesite bricks for the lining of O.H. furnaces dealing with the rapid increase in demand in the last fifteen years, a comparison of the various linings employed, the costs for repairs broken down to the various parts of the furnace, furnace efficiency and the operation of the furnaces (acid or basic), and the quality of the steels produced.—T. G.

On Chromospinellides in the Magnesite–Chromite Refractory of an Old Furnace Lining. V. V. Goncharov. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **110**, (4), 617–619). [In Russian]. This is a microscopical and chemical study of an O.H. furnace refractory brick made up of 70% calcined magnesite and 30% chromium spinel ore. It is found that the spinel crystals are enriched in Fe_2O_3 in the high temperature zone. X-Ray analysis shows that the unit cell spacing is increasing with the increase of iron. It is suggested that Cr_2O_3 is partially replaced by Fe_2O_3 and MgO by FeO.—S. I. T.

IRON AND STEEL—GENERAL

Iron and Steel Manufacture in the Barrow Area. T. G. Marple. (*Iron Coal Trades Rev.*, 1957, **174**, Feb. 1, 251–253). A brief historical review with notes on recent developments.

Iron and Steel, Heavy Industry. P. Epron. (*Arts et Manuf.*, 1957, Jan., 34–35). A review of the industry in France.

The Jernkontoret and the Swedish Iron Industry. (*Berg-Hüttenmänn. Monatsh.*, 1955, **100**, Dec., 307–314). A history of the Swedish iron and steel industry is given with emphasis on the role of the Jernkontoret. This latter was firstly an administrative policy-making body, but soon became mainly concerned with technical progress. Sweden's abundance of good quality ores, forests, and hydro-electric power but lack of coal has led to the development of the electric smelting furnace, the sponge iron process, and high developments of the acid Bessemer, acid open-hearth, and acid electric arc processes for high quality steels. The present research organization of the Jernkontoret is described.

Furnace Maker Visits Russian Steel Mills. (*Steel*, 1956, **139**, Aug. 27, 88–90). Impressions are given from a 3-week visit to Russian iron and steelworks. No unusual automation in rolling mills was noticed. Rolling practice at 2 plants was below U.S. standards. The 5 blast furnaces at Zaporozhe operate with top pressure, 95% sinter, and balanced-moisture blast. Oxygen content of air to open-hearth burner ports is brought to 25%.—D. L. C. P.

Steelmaking: Portrait of Tomorrow. (*Steel*, 1956, **139**, Sept. 17, 137–142). Likely trends in iron and steel making processes are predicted. Blast furnaces will remain in favour helped by burden preparation, top pressure, blast conditioning, and external desulphurization. Open hearth practices will reduce the length of heats.—D. L. C. P.

Iron Extraction Now and in the Future. R. Durrer. (*Berg-Hüttenmänn. Monatsh.*, 1955, **100**, Oct., 275–280). This lecture traces the development of the iron and steel industry from the smelting forge to modern blast, electric smelting and low shaft furnaces, and the sponge iron process and oxygen steelmaking processes. It then discusses the future of the industry with special reference to Latin America. The large iron ore deposits but comparative lack of coal in that area suggest that the new processes are likely to be advantageous: the area will also become a major exporter of iron ore.

Ten Years Progress in Iron and Steel Making. E. Greiner. (*Acier Stahl Steel*, 1957, **22**, Jan., 17–26). [In French]. Recent developments in the making and shaping of iron and steel are described. These include: the low shaft blast furnaces, the Krupp-Renn process, the Lubatti process, the H-iron process, the de-siliconization and desulphurization of iron, developments in O.H. and electric furnaces, new converter processes, the L–D process, the continuous casting of steel, and developments in the continuous hot and cold rolling of steel.—M. D. J. B.

Year of Achievement in British Steel. (*Iron Coal Trades Rev.*, 1957, **174**, Jan. 4, 15–25). A review of output, costs, new plant, ores, wages, and research is presented.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Reconstruction of the Kokura No. 1 Blast Furnace. Y. Doi et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 794–795). [In Japanese]. Details of the lines and refractories used are given for the furnace and its hot-blast stoves.—K. E. J.

A Study on Blast Furnace Operation under Reducing Conditions. G. Tada et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 795–796). [In Japanese]. The ratio Ks-si is $(S)/[S][Si]^{\frac{1}{2}}$, where (S) is the % of sulphur in slag and [S] that in the iron. Its relationship with percentage of sinter is shown as a smooth band with a maximum at 65% sinter (CaO/SiO_2 ratio nearly 1·4). Results for its variation with CaO/SiO_2 at different sinter percentages are compared with curves given by W. Oelsen. An inverse linear variation is shown between Ks-si and CO/CO_2 ratio.—K. E. J.

Study on the Blast Furnace Reaction by Rapid Cooling of Burdens. N. Nakamura et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 797–798). [In Japanese]. Nineteen sampling positions are shown for an 8-ft high experimental furnace, and values of the carbon, sulphur, and iron percentage at each are given.

On the Control of Blast Furnace Operation by the Shaft Temperature. M. Fukushima et al. (*Tetsu to Hagane*, 1956, Sept., 798–799). [In Japanese].—K. E. J.

Some Studies on Distribution of the Charge in the Model Blast Furnace. T. Mimura et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 713–714). [In Japanese]. Experiments with a laboratory " slice " model show the effect of lowered stock level on the distribution of the charge, variations in thickness across the furnace of an ore layer of constant size when different sizes of coke are charged, and the effect on distribution of using the Stähler charging mechanism.—K. E. J.

High-Temperature Liquid-cooling of Blast Furnace Tuyeres. K. Schilcher. (*Stahl u. Eisen*, 1956, **76**, Sept. 20, 1229–1231). The reasons for tests on high-temperature liquid-cooling are given and some technical details are discussed. The temperature conditions in the tuyere are considered. Test results are given.

" Hot " Cooling of Tuyeres. (*Foundry Trade J.*, 1957, **102**, Feb. 14, 220). An account of the German blast-furnace tuyere cooling process and its possible extension to cupolas and electric-arc foundry furnaces. Pressure has been raised to

5 atmospheres with a saving of cooling water (reduced to one-sixtieth), heat recovery, and improved control.

Investigation of the Refractory-lining Wear in Metallurgical Furnaces with the Aid of Radioactive Isotopes. P. L. Gruzin and S. V. Zemskiĭ. (*Zavodskaya Laboratoriya*, 1956, **22**, (2), 169–177). [In Russian]. The theory and practice of the use of radioactive isotopes for following the wear of refractory linings in blast furnaces is discussed. Most attention is paid to the blast-furnace stack and hearth-pad. The arrangement of sources and circuits adopted for the central registration of their activity for a stack lining having 36 sources divided equally between three levels, is described. A slightly different technique was used for mixer and O.H. furnace linings. For the blast-furnace hearth, ^{60}Co was used in the carbon and ^{192}I in the fireclay parts. ^{32}P is recommended for the upper layers of the pad. Some other possible isotopes are considered.—S. K.

Influences of Gas Reducibility in the Blast Furnace on the Microstructure of Pig Iron. S. Kamatani et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 801–803). [In Japanese].—K. E. J.

Theoretical Study of Factors Affecting the Percentage of Carbon Monoxide in Blast Furnace Top Gas. K. Ono et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 799–801). [In Japanese]. Various formulæ are derived, and results from an operating furnace, an experimental furnace, and an experimental low-shaft furnace are used to show a graphical relationship between the CO in the gas and an expression including the ore reduction time, coke rate, and coke size.—K. E. J.

Study on Pressure Loss and Heat-transfer in the Packed Column. R. Ichiyasu et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 868–869). [In Japanese]. In the apparatus described, a packed column is heated in a propane-fired furnace, and pressure measurements are made. The relationships between pressure loss and rate of discharge of gas from the column are established for various temperatures up to 450° C.—K. E. J.

Gas Turbines for Blast Furnace Blowing. W. Runte. (*Stahl u. Eisen*, 1956, **23**, Nov. 15, 1579–1581). A review of the paper by C. E. Sayer in the *J.I.S.I.* 1955, **179**, 359–371 with some annotations on German conditions.

On a Crack in the Cottrell Insulator for Cleaning Blast Furnace Gas. K. Inoue. (*Tetsu to Hagane*, 1956, **42**, Sept., 916–918). [In Japanese]. Dust deposited on a broken insulator was examined for contents of zinc, chloride etc.—K. E. J.

Concentration of Blast Furnace Flue Dust. S. B. Das Gupta and P. I. A. Narayanan. (*J. Sci. Indust. Res.*, 1957, **16A**, Jan., 42–44). Iron-rich concentrates suitable for use after sintering were studied. Analyses of Tata flue dust are given, and the same after tabling. Magnetic separation raised Fe to 56·43%. The mineralogical constituents were determined.

Study of the Clarification of Water from the Wet Cleaning of Blast Furnace Gas. P. Pelzer. (*Rev. Tech. Luxembourg*, 1956, **48**, Oct.-Dec., 191–197). The general problem of the removal of solid material from water used in gas cleaning is first discussed. The new plant of H.A.D.I.R. at Differdange, which employs a Dorr-Oliver thickener is described with illustrations.—B. G. B.

Fuel and Power Balance in Ironworks. J. Syczeniowski. (*Iron Coal Trades Rev.*, 1957, **174**, Feb. 15, 385–388). Blast furnace heat balances and recent improvements are considered. Fuel economy measures by reduction of gas leakage, gas cleaning, improved power houses, and use of gas turbines are surveyed. The effects of sintering are included.

Iron and Steel Production in Countries Poor in Raw Materials. H. Schenck. (*Iron Coal Trades Rev.*, 1956, **173**, Dec. 21, 1489–1491). Alternatives to the blast furnace are reviewed and the choice of steel process briefly considered. Such countries, and their sources of fuel, are mentioned.

The Reduction of Iron Ores. The Possibilities of an Alternative to the Blast Furnace. S. G. Cope. (*Murex Review*, 1957, **1**, (17), 465–497). A review of processes intended to displace the blast furnace including electric furnaces, low-shaft, rotary and similar modifications, direct processes with solid or gaseous reducing agents, retort, shaft, and rotary furnaces including the Domnarfvet and Krupp–Renn rotary and Wiberg–Söderfors shaft furnaces, and the Norsk–Staal and Madaras processes with discussion of the present position.

Industrial Reduction of Iron Ores by Hydrogen. A. Roos. (*Genie Civil*, 1957, **134**, Jan. 15, 36–39). An account of laboratory investigations of the mechanism and course of reduction is followed by a brief account of the pilot plant of Bethlehem Steel at Trenton, N.J. A flow sheet is given.

On the Carbon of Charcoal Pig Iron. T. Yasumoto. (*Tetsu to Hagane*, 1956, **42**, Sept., 807–809). [In Japanese]. Chemical analyses for carbon and other elements between charcoal and normal pig iron are compared, and the variations of carbon content during tapping and at different levels in the metal are given.—K. E. J.

Study on the Manufacture of Pig Iron and Portland Cement in Shaft Furnaces. II. On the Weight of Moving Gypsum in Manufacturing Portland Cement. K. Takahata et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 908–910). [In Japanese]. Mortars were made from cements produced from slags (analyses given) with up to 6% additions of calcium sulphate. Results are given for strength tests after 3, 7, and 28 days.—K. E. J.

Low Temperature Smelting in the Low Shaft Furnace. H. Reinfeld. (*Radex-Rundschau*, 1956, May, 91–104). The growth of the iron and steel industry and the increasing demand for raw materials is considered with regard to the possibility of pelletizing and sintering fine ores and the use of poorer coking coals. Research work on the technical and economic aspects of raw material preparation and the manufacture of ore-coal briquets and the low temperature smelting of these briquets in a low shaft blast furnace are described. Economically the low shaft furnace compares well with other methods of pig iron manufacture.

A Contribution to the Determination of Optimum Grain Sizes in Shaft Furnaces. J. Tischendorf. (*Neue Hütte*, 1956, **1**, Sept., 456–457). Results are reported of investigations, based on sieve analyses, into the effects on low-shaft furnace operation of iron ore breakage.—L. J. L.

Slag Regulation in the Production of Manganiferous Pig Iron in the Low Shaft Furnace. G. Brückner. (*Neue Hütte*, 1956, **1**, Sept., 449–456). The effect of slag composition on the heat of fusion, melting temperature, and viscosity; the optimum slag composition for normal blast operation; the effect of oxygen-enriched blast on basicity and manganese production; and methods of melting Portland cement slag in low shaft furnaces are discussed.—L. J. L.

Principles for the Determining of Dimensions of Krupp–Renn Process Rotary Furnaces. J. Mach. (*Czech. Heavy Ind.*, 1957, (1), 25–35). An illustrated discussion of the process with some account of furnace output and its relation to length and diameter of furnace and time of passage, filling, revolutions, and other factors.

Experimental Production of Pig Iron and Steel from Cominco Iron Concentrates. B. G. Hunt, E. J. Kwasney, W. P. Campbell, and S. L. Gertsman. (*Trans. Canad. Inst. Min. Met.*, 1955, **58**, 147–157). A sulphide concentrate from a lead–zinc ore is roasted to produce acid. The oxide calcine was smelted in an experimental 75 kw electric furnace and 6 t of pig produced. This with or without scrap and commercial pig iron was used in a basic electric steel furnace and metallography and mechanical properties of the products were determined. The products were satisfactory.

TREATMENT AND USE OF SLAGS

Production and Application of Foamed Slag. W. Ruopp. (*Stahl u. Eisen*, 1957, **77**, Jan. 10, 36–43). The production of foamed slag rose in the U.S.A. from 0·5 million tons in 1945 to more than 2 million tons in 1953, i.e. it has become an important material in the building industry for heat insulation either alone or as an addition to concrete. Its bulk density varies between 0·25 and 0·9 kg per litre and its thermal conductivity is as low as 0·09–0·14 kg cal/m/h/° C according to its bulk density. The author describes the various processes for the production of pumice slag and discusses the factors that affect porosity such as slag composition, temperature, type of foaming, viscosity of the slag, etc. In Rheinhausen, the slag is poured into a foaming bed (about 9 m^3 at the time) and high-pressure water enters the bed through a great number of nozzles. At the same time the bed is tilted in order to keep the slag moving. The foaming is of short duration and during this time the slag shows a vibrating or boiling movement. After solidification the water is turned off, the residual water drained from the bed, and the slag left for a few minutes in order to give good crystal formation of the slag and eliminate internal stresses.—T. G.

Recovery of Alumina from Blast-Furnace Slag for the Aluminium Industry. O. Vorwerk, P. Hüttemann, R. Mintrop, and G. Roederer. (*Stahl u. Eisen*, 1956, **76**, Nov. 29, 1628–

1634). The authors describe the Séaille process for the recovery of alumina from blast furnace slag. The blast furnace is operated so that the slag is basic and rich in alumina; the alumina is then recovered with soda. The authors report on a trial run with a Portuguese–Indian ore mixture at Rheinhausen, in particular its metallurgical aspects, and on the transition from, and back to, normal operation. The alumina content of the slag varied between 27·5 and 29%; the efficiency of the recovery was 90·95%.—T. G.

The Solubility of Basic Converter Slags in Citric Acid. A. Decker, A. Delsa, and R. Sevrin. (*Rev. Univ. Min.*, 1956, 9th series **12**, Dec., 652–660). The influence of SiO_2, P_2O_5, CaO, Fe, and the SiO_2/P_2O_5 ratio on the solubility of basic converter slags in citric acid has been studied, and also influence of particle size. A statistical analysis of the results has been made.—B. G. B.

The Composition of Anosovite and Titanium Sesquioxide in Titanium-rich Slags. V. V. Lapin, N. T. Kurtzeva, and O. P. Ostrogorskaya. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **109**, (4), 824–827). [In Russian]. Chemical analysis of anosovite and Ti_2O_3 extracted from titanium-rich slags suggest that the original formula proposed for anosovite (Ti_3O_5) is rather too simple and that anosovite has a brookite type of structure.

Activities in Liquid Slags. P. T. Carter. (*Royal Technical College Metallurgical Club Journal*, 1955–6, (8), 43–46). Four ternary diagrams are given in part, and the systems discussed: FeO–CaO–SiO_2, FeO–MnO–SiO_2, FeO–CaO–P_2O_5, and CaO–MnO–SiO_2.

PRODUCTION OF STEEL

Steel Production Today. R. L. Knight. (*Australasian Eng.*, 1956, **48**, July 7, 48–55). This paper outlines the history and present utilization of the four main steelmaking processes and of the continuous casting process. The oxygen blown converter is fully described and its efficiency is compared with that of the open hearth furnace. Possible future developments of the processes are discussed. The new 275-ton O.H. furnaces at the Port Kembla works of the Australian Iron Steel Co. are described in detail.

Productivity in Steel. E. Ford. (*Brit. Steelmaker*, 1957, **23**, Mar., 76–77). Possible directions for further development are briefly indicated with reference to recent economic theory.

Technical Developments in the Steel Industry. Some Lessons from Sweden. D. J. O. Brandt. (*Iron Coal Trades Rev.*, 1957, **174**, Jan. 25, 197–200). A brief historical review with a discussion of the fuel problem with notes on recent developments and the Research Organizations.

Transport of Blast-furnace Metal by Water. (*Iron Coal Trades Rev.*, 1957, **174**, Feb. 22, 440). Transport of molten pig-iron on the Rhine from Hochfeld to Hamborn will begin this year. Ships carrying 200 tons and returning with billets have been constructed.

Rotor Steelmaking Process. (*Iron Coal Trades Rev.*, 1957, **174**, Feb. 22, 437–440). Further details are given, particularly on control by the CO in waste gas. Efficiency, steel quality, and economic prospects are discussed and it is concluded that the process costs less than the O.H. and about the same as the basic Bessemer.

Principles of Steel Making in the Rotor and Results Obtained. R. Graef. (*Stahl u. Eisen*, 1957, **77**, Jan. 10, 1–10). A new process of steel making is described, which has been on trial since 1952. The process can be used for pre-treatment of iron for both the basic converter and the open-hearth furnace, or for the direct production of steel. To the blast furnace is attached a 60-ton capacity "rotor" or kiln. Ore and lime are fed into the kiln before the iron of the blast furnace is charged. Pure oxygen is used for blowing through two jets, one immersed in the molten metal and the other above it. Blowing time varies between 50 and 60 min while the kiln is rotated at 0·1–0·5 r.p.m. The O_2 from the immersed jet oxidizes the carbon to CO and the O_2 from the second jet completes the oxidation to CO_2. Contrary to the succession in the basic-Bessemer converter, dephosphorization takes place in the rotor before the elimination of the carbon. Desulphurization is better in the rotor than in the converter or open-hearth furnace. The nitrogen level varies around 0·004%. The slag is about 40° C hotter than the molten metal, i.e. similar to the conditions in the open-hearth furnace. The author discusses the metallurgical and economic aspects of the process.—T. G.

The "Kaldo" Rotary Oxygen Steelmaking Process. B. Kalling and F. Johansson. (*Iron Coal Trades Rev.*, 1956, **173**, Dec. 21, 1497–1499). A tilting surface-blown converter which achieves mixing by axial rotation, up to 30 r.p.m., is described. High-phosphorus metal can be used with success.

The "Kaldo" Steelmaking Process in Operation. D. J. O. Brandt. (*Iron Coal Trades Rev.*, 1957, **174**, Feb. 8, 325–327). An account of the Kalling-Domnarfvet kiln process as witnessed by the author. A 30-ton unit is described and control and future developments are discussed.

Tonnage Oxygen. The Field of Application in Steelmaking. F. J. Clark and J. L. Harrison. (*J. Iron Steel Inst.*, 1957, **186**, July, 305–323). [This issue.]

Electric Power for Steel Production. A Review of Equipment Available from the United Kingdom with Particular Reference to the Durgapur Project. (*Overseas Eng.*, 1957, **30**, Feb., 234–238). An account of equipment with a review of orders actually placed.

New Trends in Steelworks Ventilation Problems. G. Willdeck. (*Blad Bergs. Vanner*, 1956, **32**, (4), 353–395). [In Swedish]. This is a lengthy paper presented at the 92nd Annual Meeting of the Society held on Jan. 28 at Orebro (Sweden). The author deals in great detail with the problems connected with ventilating steelworks of various types—rolling mills, foundries, blast furnaces, etc.—involving those of heat, air exchange, smoke, dust, also poisoning beginning with observations from the medical viewpoint. Several working drawings of the different ventilating appliances available appear together with diagrams of ventilation schemes for the different kinds of plants. The paper concludes with a discussion in which several Swedish ventilation engineers participated.

Fuel Conservation in the Steel Industry. R. F. Perkins. (*Research*, 1957, **10**, Feb., 42–47). A survey of the principal sources of heat loss is given and a series of experiments on ingots is reported. Heat loss was measured and extent of solidification calculated from observations on the mould as direct methods involve sacrifice of the ingot. Recommendations for casting bay and soaking pit practice are made.

Significance of Waste Heat and Heat of Cooling in the Organization of Heating, Power and Water Supply in Steel Works. F. Wesemann. (*Stahl u. Eisen*, 1956, **76**, Sept. 20, 1221–1223). Exhaust heat and cooling losses are discussed, and the author reviews methods of calculation and possibilities of new developments.

Steelworks Experience in Conversion to Waste Heat and High-temperature Liquid-cooling Plant for Supplying Steam. E. Pracht. (*Stahl u. Eisen*, 1956, **76**, Sept. 20, 1224–1229). Existing conditions and lines of development in the steam supply organization of a steelworks are reviewed. The author discusses waste heat utilization and the high-temperature liquid-cooling of various types of furnace.

Water in the Steel Industry. P. Mosel. (*Rev. Tech. Luxembourg*, 1956, **48**, Oct.-Dec., 208–210). A short review of the consumption of water in the steel industry and the purification of water after use is presented.—B. G. B.

Andrews Toledo Centenary, 1856–1956. (*Brit. Steelmaker*, 1956, **22**, May, 124–127). A brief historical review and account of the works today.

Modernization of an Industrial Plant Distribution System. A. C. Stoever. (*Iron Steel Eng.*, 1956, **33**, Nov., 89–92). Steel works electric power plant is reviewed from the viewpoint of supply contracts and their provisions.

Monolithic Converter Linings. J. Davies. (*Inst. Brit. Found. Australian Branch, Convention* 1956, 39–50). A rammed quartz lining, bentonite-bonded, and graded to maximum packing density is described.

Desulphurization in the Basic Converter. J. Wampach and A. Decker. (*Rev. Mét.*, 1955, **52**, Nov., 887–894). The advantages of screening the lime prior to use in the converter are discussed. The various factors influencing desulphurization during a basic converter heat, especially the manganese content of the metal, slag basicity, and type of blast are considered in the light of results achieved in practice.—B. G. B.

Basic Converter Practice Attempting Chromium Removal. T. Tanaka, A. Muramatsu, T. Maruo, and T. Watanabe. (*J. Mech. Lab.*, 1956, **10**, Nov., 230–236). Oxygen-enriched blowing of a side-blown converter is studied. Chromium removal is better and temperature lower the more FeO is in the slag. At 1600° C about 96% Cr is removed and finished steel below 0·1% Cr is easily obtained.

Oxygen-Blown Steel. A. C. Lopes. (*Eng. Min. e Met.*, 1956, **23**, Jan., 31–33; Feb., 85–88). [In Portuguese]. The various commercial processes for the conversion of liquid iron to steel are reviewed under two main headings; those using all oxygen (the L–D, Kalling, Bulle, and MA processes) and those using diluted oxygen (about a dozen). Plant for oxygen conversion of iron is being employed in Brazil.—P. S.

Pretreatment of Hot Metal in the [Inactive] Mixer. K. Narihiro et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 803–805). [In Japanese]. Results are given which show the effects of oxygen blowing on the temperatures and compositions of the metal and slag.—K. E. J.

Some Methods for Analyzing and Controlling an Open Hearth Operation. E. H. Swett. (*Iron Steel Eng.*, 1956, **33**, Nov., 109–113). Control charts, their construction and interpretation, and controls resulting from the data so prepared are discussed.

New Open Hearth Boosts Steel Production. J. McAllister. (*B.H.P. Rev.*, 1956, **34**, Dec., 4–9). An account of the new Port Kembla plant. Its capacity is 350,000 t per year. Construction features, control, and various special features are described. It is a shallow hearth furnace adapted to the scrap-hot metal process.

Reconstruction of the Siemens Furnace and its Effect. S. Yamamoto et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 919–920). [In Japanese].—K. E. J.

Reconstruction of Air Uptakes (from Double to Single) of O.H. Furnace, and Its Result. K. Nagami et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 746–747). [In Japanese]. The conversion resulted in a 15% increase in oil consumption per hour, increases of over 50% in the life of bricks in the end and side walls, a substantial reduction in the ratio of time for repair to operating time, and an increase in productivity from 6·48 to 7·25 tons/h.—K. E. J.

Hydrogen in Steelmaking Slags. J. H. Walsh, J. Chipman, T. B. King, and N. J. Grant. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Nov., 1568–1576). Using a modification of the vacuum fusion method, the authors have analysed synthetic slags brought into equilibrium with atmospheres containing hydrogen or water vapour, and show that only water vapour dissolves in slags. Slag and metal samples from industrial heats have also been analysed, confirming the important role of the slag in determining the hydrogen content of the metal. The differences noted in acid and basic O.H. and basic electric furnace practices are tentatively explained.—G. F.

On the Chemical Reaction between Carbon-saturated Molten Iron and CaO–Al_2O_3–SiO_2 Slag. II. The Effects of FeO, MnO and Na_2O Addition. M. Soga. (*Tetsu to Hagane*, 1956, **42**, Mar., 169). [In Japanese].—K. E. J.

Study on the Sampling Methods of Molten Steel in Oxygen Analysis and Influence of the Slag Basicity on Oxygen Contents in Molten Steel. H. Kunitake. (*Tetsu to Hagane*, 1956, **42**, Mar., 371–372). [In Japanese]. The influence of sampling method (spoon tests in various conditions; bomb test) on the analysed oxygen content for steels of carbon content between zero and 1·0% is shown. The relationship between the oxygen content of the steel and the total FeO content of the slag is also indicated for various ranges of slag basicity.—K. E. J.

Elimination of Hydrogen and Nitrogen in Molten Steel with Argon and Oxygen Flushing. II. T. Nakayama. (*Tetsu to Hagane*, 1956, **42**, Mar., 288–290). [In Japanese]. Results show that argon and high-purity (99·8%) oxygen can be equally effective in reducing contents of hydrogen and nitrogen. Relationships between flushing volumes and the nitrogen reduction are shown. The increase in decarburization velocity as hydrogen content decreases is illustrated.—K. E. J.

The Bessemer Process in the U.S.A. H. B. Emerick. (*Stahl u. Eisen*, 1956, **76**, Aug. 9, 1024–1028). Characteristics and range of application, converters, raw materials, melting processes, finishing processes, de-phosphorization, nitrogen absorption, and both the present position and future development of the Bessemer process in the U.S.A. are reviewed.

The Pre-Blowing Plant of the Eisenwerk-Gesellschaft Maximilianshütte A.G. at Sulzbach-Rosenberg. J. Sittard. (*Stahl u. Eisen*, 1956, **76**, Nov. 15, 1554–1561). The author describes the methods used at Sulzbach-Rosenberg for the pre-blowing of converter iron with pure oxygen for reducing the silicon content of the iron and raising at the same time its temperature. The manganese content was also reduced by pre-blowing. Two methods were used: pre-blowing in the holding furnace and in the ladle. The oxygen consumption in the furnace was about 5 m³ per ton of iron, blowing time varied between 4 and 36 min with an average of 13 min, Si and Mn removed, 43 and 33%, respectively. Oxygen consumption in the ladle was 2·5–4·5 m³ per ton of iron, blowing time 1·5–3 min, Si and Mn burn-off 41 and 20% respectively. The wear of the ladle by pre-blowing is increased by about 30%. Blowing time in the basic-Bessemer converter could be reduced from 14 to 10·5 min for pre-blown iron; the nitrogen content was reduced from 12·5 to 10% and the phosphorus content from 0·047 to 0·04%.—T. G.

Fine De-phosphorisation in the Basic Bessemer Converter. H. Rellermeyer and T. Kootz. (*Stahl u. Eisen*, 1956, **76**, July 26, 965–968). The activities of ferrous oxide and calcium oxide in the system FeO–CaO–P_2O_5, the effect of the basic nature of the slag on the oxygen and phosphorus contents of the steel, the influence of temperature on de-phosphorization, the effect of soda, and finally the industrial implications of the considerations adduced are among the matters discussed.

Temperature Measurement in the Basic Bessemer Converter during Blowing. H. Knüppel, K. E. Mayer, G. Wiethoff, K. Doffin, and W. Koch. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1410–1416). The radiation pyrometer incorporating a Siemens Ardonox cell of special design and its operation and compensation is described in detail. The readings of the radiation pyrometer are compared with those obtained with a spectrometer and an immersion thermocouple. Response time of the radiation pyrometer is 10 s. When measuring charges blown with air, the fumes affect the temperature readings by about 10° C, i.e. within the accuracy of the method, but when blowing with oxygen-enriched air, a correction is necessary. Difference between radiation and immersion measurements was about 12° C.—T. G.

Spectrographic Investigation of the Basic Bessemer Converter Flame. F. Wever, W. Koch, H. Höfermann, H. Knüppel, K. E. Mayer, and G. Wiethoff. (*Stahl u. Eisen*, 1956, **76**, Aug. 9, 1032–1040). The apparatus and experimental method are described and the results of the investigation are given. The authors discuss the spectrum obtained during decarbonization and dephosphorization, the changes in the spectrum at stages in the process, the intensity of the radiation from various parts of the flame, the interpretation of the spectrograms, the effect of flame temperature, and the influence of gas composition in the flame.

Basic Converter Practice Attempting Chromium Removal. T. Tanaka. (*Tetsu to Hagane*, 1956, **42**, 274–275). [In Japanese]. Results from a small converter with an oxygen-enriched blast give blowing times and other data for reduction of chromium contents in the iron from an average of approx. 2·0% to 0·1% (four heats) and from an average of approx. 1·1% to 0·4% (three heats).—K. E. J.

Investigation of the Mixing Characteristics of a Basic Bessemer Iron Mixer. E. Eickworth, H.-J. Kopineck, and G. Opfer. (*Stahl u. Eisen*, 1956, **76**, Aug. 9, 1028–1032). Problems of crude iron mixer operation, and model tests for their elucidation are mentioned. Experiments using the radioactive isotope ^{32}P, and trials with a full, half-full, and quarter-full mixer are described. Industrial tests are considered. The authors also refer to the improvement in mixing obtained by means of increased turbulence.

Problems of Metallurgy. Academy of Sciences of the U.S.S.R., Moscow, 1953. **Mechanical Properties of Bessemer Low-Alloy Structural Steel.** N. P. Shchapov and E. S. Volokhvyanskaya. (409–441). [In Russian]. An account is given of a comprehensive investigation of the mechanical properties of a low-alloy Bessemer steel (0·06–0·13% C, 0·28–0·64% Mn, trace–0·44% Si, 0·044–0·051% P, 0·026–0·048% S, 0·00–0·90% Cr, 0·00–0·55% Ni, 0·04–0·44% Cu, 0·013–0·018% N_2, 0·00008–0·00019% H_2, 0·00179–0·0165% O_2). The main conclusions drawn are: through alloying, the steel is actually less liable to brittle fracture than the corresponding O.H. steel and has a higher yield point; the ageing properties and sensitivity to stress-concentration in cyclic loading remain relatively poor. It is suggested that by using other measures in addition to alloying, the properties of Bessemer steel can be improved still further. **Investigation of Processes Occurring during the Tempering of Hardened Steel.** K. F. Starodubov. (442–450). Changes occurring in hardened steel during tempering, mainly at 300–550° C, are described and explanations are proposed. **Primary Structure**

of the Ingot and its Effect on the Properties of Steel. A. P. Pronov. (451–456). Unlike the finely crystalline primary structure of a carbon steel ingot, a dendritic one is characteristic of correct production conditions and results in good mechanical properties both at high and low temperatures. Factors governing the type of primary structure formed have been partially elucidated. **Main Questions in the Rail Problem.** L. L. Pinkhusovich. (457–461). The problem of rail quality as it has been dealt with in the U.S.S.R. is reviewed and the main factors involved are discussed.—S. K.

New Oxygen Steelmaking Process Cuts Cost; Boosts Quality. T. Campbell. (*Iron Age*, 1956, **178**, Oct. 18, 126–129). The principles and operation of the " Kal-Do " steelmaking process are described. Developed by the Stora Kopperberg Corp. (Sweden), the first plant has been in production since May 1956. The furnace, containing a 30-ton charge, rotates at 30 r.p.m. while oxygen is blown on to the bath. The major advantages reported are: clean quality steel at lower cost, carbon level can be controlled without recarburization, economic use of iron ore as cooling agent.—D. L. C. P.

Aerodynamic Constitution of the Open-hearth Furnace. I. Functions of Constituents. II. Features of Typical Designs. H. Hashimoto. (*Tetsu to Hagane*, 1956, **42**, Mar., 299–300; 301–302). [In Japanese]. Results from model experiments show gas patterns for separated and combined air uptakes, those at roof and burner level produced by the side wall, and mixing contours across a central section between the uptake and the first charging door of a single-uptake model for the port roof inclined 26° downwards and 1° 30′ upwards. The gas mixing at the last-mentioned section, for the port roof inclined 26° downwards, is shown for the incoming and outgoing periods, the fuel/air ratio being 1/12.—K. E. J.

A Practical Suspension for Insulating Refractory Walls and Arches. (*Iron Steel Eng.*, 1956, **33**, Dec., 149, 151–152, 155). A stainless steel supporting clip is used.

Problems of Metallurgy. Academy of Sciences of the U.S.S.R., Moscow, 1953. **Electrochemical Investigations in the Field of Pyrometallurgy.** O. A. Esin. (64–72). [In Russian]. Work on a number of high-temperature galvanic cells with fused slags as the electrolyte is described. These have been studied electrochemically and include cells with an iron electrode. Electrocapillary effects have also been studied. The kinetics of metal/slag reactions are discussed. **Influence of Deoxidizing Elements on the Activity of Oxygen Dissolved in Liquid Iron.** A. M. Samarin. (76–98). Equilibria between oxygen in liquid iron and silicon, vanadium, and other deoxidizing elements are considered, and the influence of these elements on the activity of the oxygen is assessed. **Radiating Power of the Steel Bath in the Near Infra-Red Range of the Spectrum.** D. Ya. Svet. (99–106). The importance of the infra-red range in pyrometry is discussed and some pyrometric apparatus using this range is described. Results of emissivity determinations on surfaces of liquid pure iron, pig iron and carbon steel with additions of vanadium and chromium are presented. **Some Problems of the Theory of Furnaces.** M. A. Glinkov. (276–290). Furnaces are classified and the underlying theory is discussed. Special attention is given to radiational heat transfer, combustion, gas flow and furnace design being considered. **Increasing Charge-Weight as One of the Main Lines of Technical Progress in O.H. Steelmaking in the U.S.S.R.** P. Ya. Kravtsov. (291–294). The continually increasing size of Soviet O.H. furnaces is discussed and the influence of furnace size on tap-to-tap time is briefly considered. **The Large-Tonnage O.H. Furnace.** Ya. A. Shneerov. (295–300). A brief account is given of changes in O.H. furnace size and operation, with examples of size changes without appropriate changes in design. **Change in Steel Temperature during Teeming.** A. P. Pronov. (301–308). A method for continuous temperature measurement of steel in the teeming ladle was used to find the mechanism of cooling in the ladle. Metal weights of 10–40 tons and a mean teeming rate of 500 kg/min were used. **Do We Need Combined Steelmaking Processes?** K. G. Trubin. (309–314). Principles which should govern the choice of steelmaking methods are summarized, the technological advantages of several duplex and other processes are critically examined.—S. K.

First Report on the New 50-ton Open Hearth Furnace. H. Yoshihara. (*Tetsu to Hagane*, 1956, **42**, Mar., 262–263). [In Japanese]. Operating particulars and fuel and refractory consumption figures are given for two periods during the first ten months of working.—K. E. J.

Operation of a 50-Metric Ton Siemens-Martin Furnace Fired with Natural Gas and Oil. B. Matuschka and G. Morini. (*Stahl u. Eisen*, 1956, **76**, Sept. 6, 1167–1173). The authors discuss the steelworks in Omegna (Italy), installation problems, the 50-metric ton Siemens-Martin furnace, firing, conversion from producer to natural gas, burners, fundamental thermodynamics and metallurgical conditions, advantages of natural gas firing, operating results, and automatic control equipment.

The Oxygen Content of Molten Siemens-Martin Steels During Smelting in Furnace Units of Various Sizes. K. G. Speith and H. vom Ende. (*Stahl u. Eisen*, 1956, **76**, Sept. 6, 1161–1167). The oxygen uptake in Siemens-Martin furnaces is discussed, and theoretical considerations are adduced. Among matters dealt with are: the temperature dependence of oxygen, carbon, manganese, and iron contents in slag, the effect of previous carbon content on the magnitude of the oxygen content, the interrelation between temperature, refining rate, iron contained in the slag, manganese contained in the melt, and oxygen dissolved in the steel.

Study on Melting and Refining Practice of Tilting O.H. Furnace. M. Oishi. (*Tetsu to Hagane*, 1956, **42**, Mar., 263–266). [In Japanese]. Particulars are given of operating practice, a slag-thickness measuring device, the changes of physical properties of the slag during melting, and relationships between various properties of the bath as temperatures, etc. vary.

The Operation of Open Hearth Furnaces with High Pressure Coke Oven Gas. H. Kumai. (*Tetsu to Hagane*, 1956, **42**, Mar., 269–272). [In Japanese]. Comparisons between four quarters each of operation with low- and high-pressure gas show reductions in steelmaking time, increased tonnage per hour and lower fuel consumption per ton in the latter case.—K. E. J.

Studies of the Flow in the Checker Work of Open-Hearth Furnaces. K.-W. Dockhorn. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1496–1500). The author reviews British, American and German publications of the last three decades on the flow in the checker work of O.H. furnaces.—T. G.

The Temperature Changes in the Checker-brick of a Regenerator with Lamellar Packing. A. Leitner. (*Radex Rundschau*, 1956, **7**, Oct., 349–353). An approximate treatment of the heat transmission in a regenerator operating under simple conditions is given. The dissipation of heat from convection into a plate approximates to a third-order parabola and, after reflexion and return to the surface, to a parabola of the second order by overlapping. An example is given.

On the Material Control of the Steelmaking. The Influence of the Low-quality Steel Scrap on the Open-hearth Steelmaking Process. T. Matsuda. (*Tetsu to Hagane*, 1956, **42**, Mar., 268–269). [In Japanese]. Iron balances of test heats show that the yields (ratio of ingots, butts, skulls, etc. to hot metal and scrap) increase and charging times decrease as the iron content in the scrap rises from 80% to 90%.—K. E. J.

Sulphurisation by Fuel in Oil-fired Open-hearth Furnace. D. Yamamoto. (*Tetsu to Hagane*, 1956, **42**, Mar., 266–268). [In Japanese]. The contents of SO_2 and oxygen in the downtake gas are followed through the charging, melting, and refining periods, and it is shown that the amount of sulphur pick-up from the fuel decreases as the excess air ratio increases.—K. E. J.

Some Observations on Quick Repairs of Relatively Small Open-Hearth Furnaces of 10 to 20 Ton Capacity in Steel-Castings Plant. H. Weichert. (*Giessereitechn.*, 1956, **2**, Sept., 199–202). At the Frankleben steelworks fresh relining of a 10-ton furnace takes $8\frac{3}{4}$ days of which 120 hours, or 5 days, are spent on pure repair work.—L. J. L.

Study of the Flame-Temperature Radiation in an Open-Hearth Furnace. W. Pepperhoff and H.-J. Bracksieck. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1453–1456). The authors measured the flame temperatures at various parts of a gas- or oil-fired O.H. furnace (system Maerz) by a new colour-brightness pyrometer that measures temperatures up to 3000° C. The error at 2500° C is of the order of 1%; the response is not quoted. The authors claim that by use of the new pyrometer it will be possible to study the complete and complex radiation phenomena in O.H. furnaces at reasonable cost.—T. G.

Magnetic Analyser Gives Better O_2 Samples From Open Hearths. (*J. Met.*, 1956, **8**, Oct., Section 1, 1457). A diagrammatic representation is given of the Leeds and Northrup magnetic oxygen analyser, developed to give continuous and

automatic monitoring of oxygen in O.H. furnaces. It makes use of the strongly paramagnetic nature of oxygen.—G. F.

Open-hearth Furnace Fumes; Their Formation and Resulting Problems. (*Iron Coal Trades Rev.*, 1956, **173**, Nov. 30, 1311–1317). At the 47th Steelmaking Conference held by B.I.S.R.A., papers were presented on the theoretical and practical aspects of fume formation, the deposition of droplets in the O.H. furnace, and the measurement of dust content of the waste gases. A summary of the proceedings is given.—G. F.

A Thermodynamic Study of FeO–Fe_2O_3–SiO_2, FeO–Fe_2O_3–P_2O_5, and FeO–Fe_2O_3–SiO_2–P_2O_5 Molten Systems. E. T. Turkdogan and P. M. Bills. (*J. Iron Steel Inst.*, 1957, **186**, July, 329–339). [This issue].

Study on Temperature in the Steel Making Process of Low-Carbon Top-pour Rimmed Steel. K. Izu. (*Tetsu to Hagane*, 1956, **42**, Mar., 318–319). [In Japanese]. Changes of bath temperature are considered in relation to the time after adding CaO and SiO_2, and to fuel input; cooling curves are given for ladle steel with deoxidation in the furnace and in the ladle.

Study of Basic Cupola Practice. III. Basic Cupola–Acid Converter Duplex Process for the Production of Cast Steels. T. Tanaka, T. Maruo, and N. Hamano. (*J. Mech. Lab.*, 1956, **2**, 44–45). Trials on a basic midget cupola and an acid baby side-blown converter are outlined.

Preparation of Sintered Magnesite Hearths. L. A. Araujo. (*Bol. Assoc. Brasil. Met.*, 1955, **11**, Oct., 433–437). [In Portuguese]. A brief account is given of the use of calcined, powdered magnesite for hearth-making in arc furnaces of 7–60 t capacity. A mix containing 84–89% MgO is used with a grain size distribution of: 20% > 2 mm, 30% of 1–2 mm, 10% of 0·1–1 mm, and 40% < 0·1 mm. Thermocouples are built into the hearth in order to control the firing process. A life of more than 1500 heats has been obtained making unkilled steels containing less than 0·06% C.—P. S.

Induction Furnaces. A. C. E. C. (Charleroi). (*Eng. Min. Met.*, 1956, **23**, June, 329–330). A brief review of capacities and consumptions.

Study of Temperature in Electric Furnace Steel Making. T. Imada. (*Tetsu to Hagane*, 1956, **42**, Mar., 320–321). [In Japanese]. For various types of steel, data are given on horizontal and vertical temperature variations, relations between tapping and pouring temperature, the temperature drop at tapping, and relations between time of power application and temperature rise.—K. E. J.

Consideration of a Combination Graphite Rod and Low Frequency Crucible Furnace and Experimental Results. W. Gödecke and H. Rohn. (*Giesserei*, 1956, **43**, July 19, 385–389). The theoretical basis for the construction of the combination furnace is first described. Details of the construction of the furnace are then given together with illustrations. Experimental results are given for decarburizing by the addition of ore without chalk, for simultaneous phosphorus and carbon removal, for desulphurizing at different temperatures, and for refining about 0·2% carbon on a basic hearth with ideal sealing of the furnace.—R. J. W.

The Manufacture of Graphite Electrodes for Electric-Steel Furnaces. A. Ragoss. (*Arch. Eisenhüttenwesen*, 1956, **17**, Nov., 681–688). Graphite electrodes are produced from carbon and a binder. Crystal growth during graphitization is determined by the size of the elementary crystal in the initial carbon, and by the defects in it and their relative position. Petroleum- and pitch cokes are used to obtain high electrical conductivity; the binders are coal tar pitches diluted if necessary with tar oil or mineral oil. The stages of manufacture are adumbrated.—L. J. L.

Studies on Quality Improvement of Steel by TiO_2 Slag Treatment. I. On TiO_2 Slag Treatment of Basic Electric Furnace Slag. T. Shimose. (*Tetsu to Hagane*, 1956, **42**, Mar., 326–328). [In Japanese]. Chemical compositions and properties are given for several charges made under a slag containing 20·8% of TiO_2.—K. E. J.

Determination of the Types of Steel for Fabrication and their Choice as a Function of the Necessary Characteristics. L. Alba Soares. (*Bol. Assoc. Brasil. Met.*, 1956, **12**, July, 213–259). [In Portuguese]. A comprehensive review of the behaviour, heat-treatment, and applications of plain carbon, low alloy, and carburizing steels is given. Criteria governing the choice of steel are discussed. (10 references).—P. S.

The Principles of Continuous Casting of Metals. D. M. Lewis and J. Savage. (*Met. Res.*, 1956, **1**, (1), 65–116). A review of steel and non-ferrous metal casting with sections on control of pouring, heat transfer and solidification, cooling, rupture of the ingot skin, temperature distribution in ingots and metallurgical effects.

A Contribution to Continuous Casting Technology. J. Czikel. (*Neue Hütte*, 1956, **1**, Nov., 561–562). The sinking velocity of the casting is inversely proportional to its diameter. Formulæ are presented to enable sinking velocity and casting capacity to be predicted for any material and profile.—L. J. L.

Russian Research on Continuous Casting of Steel. R. Sewell. (*Iron Coal Trades Rev.*, 1957, **174**, Feb. 15, 391–394). An account based on the report by V. S. Rutes, N. A. Nikolayev, D. P. Evtyeyev, and V. P. Druzhinin in *Stal'*, Jan. 1956. A formula for depth of liquid phase is quoted and tested by observations at the Novo-Tulskii Works on continuous and semi-continuous machines and depth of liquid phase was measured by temperature observations or by use of radio-isotopes of P or S. Thickness of ingot skin is computed and the thermal processes investigated. Conclusions are drawn on the above topics, on the zone of contact, and effects of increase of speed or increase of water consumption.

Russian Developments in (Continuous) Steel Casting. T. Margerison. (*New Scientist*, 1957, Feb. 14, 29–31). A diagrammatic account.

Electronic Recorders Lead Way to Better Continuous Casting. (*Steel*, 1956, **139**, Oct. 22, 86–89). The recorders and controllers installed on the continuous casting machine at Atlas Steels Ltd., Ont. are described.—D. L. C. P.

Study on the Solidification Process of Ingots. I. Variation of Chemical Properties of Molten Steel Adjacent to the Boundary between Liquid and Solid Metal in a Large Ingot. Y. Nakagawa et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 848–849). [In Japanese]. The sampling tube is described, and details are given of the changes in C, Si, Mn, P, S, and H_2 in the sinkhead and the ingot before casting, in the tundish, and in the casting at times in the range 0–100 min (200 min for H_2).—K. E. J.

Studies on the Solidification and Segregation of Larger Steel Ingots. I. Direct Measurements of Solidification Rate by the Bar-Test. S. Onodera et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 849–850). [In Japanese]. The apparatus is described, and a curve is given for a 25-ton ingot showing height of solidification against time after casting (up to 7 hours).

Studies on the Solidification and Segregation of Larger Steel Ingots. II. Observations on Vertical Segregation Proceeding in a Melt by the Bar-Test. I. S. Onodera et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 850–851). [In Japanese]. Samples of the molten metal inside the solidifying ingot were removed on the bar, and a diagram is given of the variation of C, Mn, and P content at five different depths.—K. E. J.

PRODUCTION OF FERRO-ALLOYS

Chromium and Ferrochromium for Special Steels. C. Dingeon. (*IVe Salon de la Chimie.—Journée des Aciers Spéciaux, Versailles*, Nov., 1956, pp. 19). Occurrence and extraction processes are reviewed.

Transformation of Molybdenite to Ferromolybdenum. Office of Technical Services. (IR. 12323, 1954; *TIDU List* 590, pp. 3). Conversion to oxide and then by thermit or electric furnace process to ferromolybdenum is briefly described.

FOUNDRY PRACTICE

Production of Cast Iron. E. Thevenin. (*Arts et Manuf.*, 1957, Jan., 36–39). A general review of developments in France.

Guide for the Manufacture of Iron Castings. O. Bragonzi. (*Fonderia Ital.*, 1956, **5**, Sept., 325–336). [In Italian]. This article is a guide to mechanical engineers who have to design iron castings for machine parts. Information is given on design procedure and tolerances, on the characteristics and limits of different cast irons and their classification, on the chemical, mechanical, and micrographic analyses of irons and on heat treatment methods.—M. D. J. B.

Foundry Technology. C. Stieler. (*Z.VdI.*, 1956, **98**, Aug. 21, 1477–1479). Recent progress of foundry technology is reviewed. The topics are: nodular iron, improvements of the cupola, of moulding technique, and developments of precision casting techniques. (22 references).—J. G. W.

Progress Made in the Foundry During the First Six Months

of 1956. P. A. Heller. (*Stahl u. Eisen*, 1956, **76**, Dec. 27, 1758–1763). This is a review of (i) structure and properties; (ii) melting practice; (iii) moulding and fettling; (iv) general. (92 references).—T. G.

Foundries in French Economy. M. Olivier. (*Usine Nouvelle*, 1956, **12**, Spring, Special No., 33, 35–37, 39–41). Foundries and their products are classified and statistics are given since 1929. Specifications and other matters are discussed.

The Works of Allied Ironfounders Pty. Ltd. G. E. Miller. (*Inst. Brit. Found. Australian Branch, Convention* 1956, 93–106). A new foundry near Melbourne is described in some detail.

A Preliminary Survey of the Properties of Investment Cast Plain Carbon Steels. R. H. Dyke and T. Fitzgerald. (*Inst. Brit. Found. Australian Branch, Convention* 1956, 51–65). Heat-treated castings are compared with wrought steels. Clover leaf test blocks were used and structures and mechanical properties determined.

Application of EK Alloying Briquettes in the Foundry. K. Wagner. (*Castings*, 1956, **2**, July, 4–7; Aug., 4–7). The structure, application, behaviour, and advantages of briquetted alloys used in the cupola are briefly discussed. The use of the various types of alloying briquettes is then considered in more detail.—B. C. W.

Bentonite Deposits in Marine Cretaceous Formations, Hardin District, Montana and Wyoming. M. M. Knechtel and S. H. Patterson. (*U.S. Geol. Survey Bull.* 1023, 1956, (1–115). A note on foundry uses is included.

Modernisation in a Small Foundry. R. M. Blandy. (*Found. Trade J.*, 1956, **101**, Nov. 29, 623–627). The possibilities of modernizing the various sections of a small foundry are briefly discussed, with particular reference to the changes recently made in the author's foundry. The financial results of this modernization are summarized.—B. C. W.

Studies on the High Temperature Melting of Cast Iron. T. Shibata et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 726–727). [In Japanese].—K. E. J.

Production Factors Contributing to High-quality Grey Iron. A. W. Schneble. (*Foundry Trade J.*, 1957, **102**, Jan. 31, 131–134). The position of the jobbing shop is considered, and the importance of sand control, melting practice, cupola contour lining, instrumentation, records, and statistical control are briefly described.

Casting Design. B. Rogge. (*Product Eng.*, 1956, **27**, Oct., 190–193). Iron and steel are considered as well as Al, Cu, and Mg alloys. Thicknesses, fillets, corners, recesses, bosses, pockets etc. and tolerances and drawing practices are discussed.

A Study on Castability. X. On the Effects of Heating Velocity of Melting on [Fluidity]. K. Hori. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Sept., 549–551). [In Japanese]. Fluidity is improved by rapid heating, and, for any metal, an optimum relationship exists between maximum melting temperature, holding time, and heating velocity to give good fluidity.

Selection and Design of Equipment for Foundry Mechanisation. J. E. Waterman. (*Inst. Brit. Found. Australian Branch, Convention* 1956, 67–92). After a general introduction items required for mechanization are briefly considered. The importance of bearings is stressed.

Leyland Foundry Mechanization. (*Iron Steel*, 1957, **30**, Feb., 65–66). Cylinder block production is described.

Conveyors Boost Foundry Output. (*Steel*, 1956, **139**, Sept. 3, 84).

Continuous Air Blast Control Improves Cupola Operation. E. J. Parker. (*Foundry*, 1957, **85**, Feb., 116–119). Installation of continuous blast control on two furnaces is described and designs evolved from these are considered. Experiments on a 9-in. cupola are mentioned and the control arrangement shown. Such an experimental cupola is recommended.

Hot-Blast Cupolas in the Foundry. W. Heinrichs and W. Bruker. (*Castings*, 1956, **2**, Aug., 31, 33, 35, 36). The construction, control, and operation of the hot-blast cupola recently installed in the foundry of Fried. Krupp at Essen, is briefly described.—B. C. W.

Oxygen Blowing at the Basic Converter Plant at Rehon. de Rousiers. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1956, **13**, (11), 2229–2235). An account of the use of oxygen at this converter plant is given. It has allowed over twice as much scrap/t of steel to be used as with the previous conventional converter practice. A reduction of about 25% in the refining time and an increased ease of temperature control have also been obtained by the use of oxygen.—B. G. B.

Echos from the Autumn Meeting. (Heated Air Cupolas). (*Metalen*, 1957, **12**, Jan. 15, 7–10). [In Dutch]. Following on the report in the previous volume, the present article reproduces the discussion that took place on heated air cupolas, which dealt particularly with questions of fuel saving, iron temperature, iron composition, furnace capacity, etc. Finally the relative advantages and disadvantages are set out. It was not possible to arrive at any definite conclusions because of lack of time and the matter is to be raised again at a subsequent meeting of the NVvGT.—F. R. H.

The Use of Calcium Carbide in Cupola Melting. S. F. Carter and R. Carlson. (*International Acetylene Association, Proc.* 1951–1955, New York 1956, 260–266). Desulphurization can be accomplished in the basic-lined cupola by adding ½–4% CaC_2 in lumps. This makes increased use of scrap possible and reduces coke requirements. In the acid cupola some neutralization occurs and so reduces the effectiveness of the addition to some extent.

A Cast Iron or Steel Flask for Hand Moulding (Constructional Details). (*Fonderie*, 1956, Sept., 358–366). A detailed account is given of the design of moulding flasks.—B. C. W.

Some Observations on the Sand-Block Moulding Process. G. Trinks. (*Giessereitechn.*, 1956, **2**, Dec., 268–272). "Bore-less casting" is used in 80–90% of the foundries in the U.S.A., but is practically unknown in Eastern Germany. The two types of the process, i.e. the production of moulds with special boxes on moulding machines for bore-less casting, and with exchangeable boxes on orthodox moulding machines, are described. The operating methods and the economics of the process are discussed. Production increases of up to 30% can be attained by its introduction.—L. J. L.

Casting Winder-drum Cheeks. A. W. Bartlett. (*Found. Trade J.*, **101**, Nov. 15, 563–568). The production by loam moulding of half-drum-cheeks castings at the Fraser and Chalmers Engineering Works, Erith, is described in detail. Each casting is 22 feet in diameter and weighs over 20 tons.

Study on the Manufacturing of Iron and Steel Tubes by Continuous Casting. T. Fujita. (*Tetsu to Hagane*, 1956, **42**, Sept., 930–931). [In Japanese].—K. E. J.

Effect of Vibrations During Solidification on the Mechanical Properties of Castings on Gas-turbine Materials. J. Jagaciak and J. W. Jones. (*Found. Trade J.*, 1956, **101**, Nov. 22, 595–603). A detailed account is given of the experimental methods used and the results obtained, in an investigation into the effects of mould vibration during solidification of shell-moulded castings in H.R. Crown Max and Nimonic C75. For both alloys there was a marked improvement in the mechanical properties of the vibrated castings. With H.R. Crown Max the properties reached a maximum at $4\text{–}5 \times 10^3$ vibrations/min and then decreased as the frequency of vibration was raised to 8×10^3 vibrations/min. The Nimonic alloy showed a maximum improvement at 80 vibrations/s, a drop to the properties of the unvibrated castings at 800 vibrations/s, and then an increase up to 10^4 vibrations/s. The vibrated castings had a fine equiaxed structure as compared with the large cored dendritic structure of the unvibrated castings.

Sound Investment Castings. C. W. Schwartz. (*Foundry*, 1957, **85**, Jan., 110–115). Defects are classified, their causes given, and remedies suggested. Illustrations of typical faults are included.

Sulzer Precision Casting. W. Sulzer. (*Métaux–Corrosion–Industries*, 1957, **32**, Feb., 79–90). The lost wax and a modification, the G process, are described. Typical products are shown.

Precision Investment and Permanent Pattern Casting. J. Doškař. (*Czech. Heavy Ind.*, 1956, (1), 25–27, 30–32). Production of machine parts is described.

Investment Casting Foundry Specializes in Ferrous Castings. T. A. Dickenson. (*Foundry*, 1957, **85**, Feb., 182–184, 186). An account of the Howard Foundry Co., Los Angeles, using polystyrene.

Some Aspects of Shell-moulding Theory. A. Braybrook and B. H. C. Waters. (*Found. Trade J.*, 1956, **101**, Dec. 20, 721–729; Dec. 27, 753–762). The results of recent work on shell moulding are presented and their influence on practice is discussed. The aspects covered are (i) the factors affecting the cold strength of a shell, (ii) the hot strength of a shell, (iii) the relationship between casting size and metallostatic head for unbacked shells, (iv) resin segregation and its effect

on shell properties, (v) the hardness of shell moulds, (vi) the factors influencing the permeability of a shell mould, (vii) gas evolution from shell moulds, (viii) surface finish, (ix) the joining of shells, (x) running and feeding methods, (xi) the metallographic structure of castings, and (xii) patternplates for shell-moulded castings. In conclusion the CO_2 and shell moulding processes are briefly compared.—B. C. W.

The Surveyor's Viewpoint on Steel Castings. S. F. Dorey. (*Iron Steel*, 1957, **30**, Jan., 25–27). Common defects and their detection are reviewed.

The Influence of Mode of Solidification on the Running Property of Molten Cast Iron. M. Okamoto. (*Tetsu to Hagane*, 1956, **42**, Sept., 924–926). [In Japanese]. The running properties of 3·8% C iron melted and poured at 1500° C decrease as the silicon content increases from 3 to 6%. This decrease is progressively lessened by additions of 2% Ni; 80 : 20 Ni–Mg; and 3% Mg_3N_2. (13 references).—K. E. J.

Effect of Various Elements on the Solidification Characteristics of Cast Iron with regard to the Casting Properties. T. Kashihara et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 923–924). [In Japanese]. The effects of Cu, Si, S, Mn, P, Ce, and Mg on liquidus temperature, plasticity during solidification, and solidification contraction are discussed.—K. E. J.

Surface Structure of Blowholes in Cast Iron. G. Östberg. (*Nature*, 1956, **178**, Dec. 29, 1463–1464). Holes due to hydrogen showing a pattern of concentric circular wrinkles are described and illustrated. They occur in iron containing magnesium when water is poured on it in the ladle. The mode of formation is discussed.

How to Control Shrinkage in Grey Cast Iron. J. Allan. (*Foundry*, 1956, **84**, Dec., 88–95). The various types of shrinkage defects that occur in grey iron castings are described and the factors that may cause such defects are discussed in detail. The major causes are considered to be casting design, gating technique, and selection of the alloy in relation to design. The possibility of producing shrink-free castings by proper attention to these three factors is then briefly considered.—B. C. W.

Scabs and Thermal Cracks, their Causes and Correction. F. Hofmann. (*Giesserei*, 1956, **43**, Nov. 8, 767–768). The term 'scab' on a casting, as used in this article is first defined. The formation of scabs is stated to be due to the large expansion of quartz particles during heating. The influence of the mould material and of additions of coal dust and organic additions on scab formation is described. The origin of thermal cracks in castings and the effect of particle size of the core sand on their formation are described.—R. J. W.

Foundry Dust Control. E. Bradley. (*Indust. Heating Eng.*, 1956, **18**, June, 155–159; July, 190–193; Aug., 222–224; Sept., 248–249, 257; Oct., 293–296, 302; Nov., 332–334; Dec., 359–360; 1957, **19**, Jan., 25–27; Feb., 56–58). Dust collectors and exhaust hood design and calculations are described and the layout and dimensions of ducting systems are considered. Exhaust systems for shake-out tables are discussed and cyclones, filters, and scrubber systems outlined. Top canopy hoods are described with notes on filters and pattern shop fittings are discussed especially for sanders. Low-pressure pneumatic conveying is considered at some length, and finally calculations for such conveyors are presented.

Foundry Illumination. (*Hand. en Ind.*, 1956, **11**, Dec. 31, 571–574). [In Dutch]. This article discusses the difficult problem of adequately lighting foundries because of their high roofs and the dirty nature of the work carried out. The relative merits of three forms of lighting are explained, namely a special type of fluorescent tube containing an internal reflector allowing the light to be reflected downwards through an angle of 120°, a new type of 375 W lamp with a mirror inside the bulb that cannot be soiled, and finally the well known sodium lamp. The economics of these lighting methods are also explained in detail.—F. R. H.

Industrial Hygiene in Foundries. W. Schweisheimer. (*Australasian Eng.*, 1956, **48**, Aug. 7, 65–66). A brief review of dust problems and silicosis is drawn from various sources.

VACUUM METALLURGY

The Successful Use of Vacuum Heat Treating Methods with Atmosphere-Reactive Metals. H. L. Hovis. (*Metal Treating*, 1956, **7**; Nov.-Dec., 2–4). Stainless steel and other small watch parts are discussed.

The Treatment of Steel Melts Under Reduced Pressure on an Industrial Scale. F. Harders, H. Knüppel, and K. Brotzmann. (*Stahl u. Eisen*, 1956, **76**, Dec. 27, 1721–1728). The authors review the principles of the vacuum metallurgy of iron and steel and present diagrams showing the relation of carbon monoxide partial pressure to oxygen content as a function of carbon content of the steel and the effect of alloying additions on the solubility of oxygen in steel. An experimental plant and two pilot plants, one for an open-hearth furnace and the other for a basic-Bessemer converter are described in detail. Large charges are treated in small batches of about 4 tons each. The steel is syphoned from the ladle into the vacuum vessel. Treatment time is very short, for 4-ton charges about 30 sec. The pressure is reduced to 5–15 mm. Additional heat is provided. Heavy foaming of the steel requires a large vacuum vessel. The pumps are laid out for 6000 and 15,000 m^3/h for open-hearth and converter steel, respectively. The steel is poured directly from the vacuum vessel. Oxygen and hydrogen contents are reduced to a third of the original values but not the nitrogen. The rather high nitrogen content of 0·004% cannot be reduced any further by vacuum treatment but can be by nitride formers such an aluminium, the quantity of which can be very small as the oxygen level is very low, i.e. practically no aluminium oxide is formed. Vacuum-treated steel shows improved structure and working, machining, and corrosion-resistance properties.—T. G.

Melting by Induction. II. High Frequency Furnace Applications. F. T. Chesnut. (*Indust. Heating*, 1956, **23**, Nov., 2356, 2358, 2360, 2362, 2364, 2368, 2370). A general review with illustrations, including an account of vacuum methods, is given.

REHEATING FURNACES AND SOAKING PITS

Heating and Soaking of Ingots for Forging. F. W. Jones and A. Barker. (*Iron Steel Inst. Spec. Rep.*, 60, 1957, 40–52). Calculations to find soaking time required to obtain a degree of uniformity adequate for ingots between 20–100 in section heated at various rates are reported, both in heating and in reheating. Two approximate methods were used and the results are presented in a form suitable for practical application. In the discussion, a caution against the too close adherence to the curves given was suggested as they are based on symmetric heat flow.

Establishing Soaking Pit Schedules from Mill Loads. R. D. Hindson and J. Sibakin. (*J. Met.*, 1955, **7**, Oct., 1105–1112). Temperatures, times, capacity, and safe maximum mill drafts are correlated with fluctuations in current or load of the bloom mill drive. Total delays, rolling schedules, mill delays and track times are also considered. It is concluded that the current of the bloom mill driving motor is mainly affected by size of draft. Change of pit temperature below 50° F has probably little effect. Minimum pit times are given for size of ingot and safe drafts are recommended. The other factors named also give rise to recommendations.

Improvements of Operation by Reconstruction of the Triple-fired Ingot Reheating Furnace. T. Yoshinari. (*Tetsu to Hagane*, 1956, **42**, Mar., 182–184). [In Japanese]. Details are given of a triple-zone reheating furnace before and after reconstruction, together with temperature distribution at eleven points and heat consumption in the zones; a higher maximum temperature and more even temperature drop are obtained, with a lower fuel consumption.—K. E. J.

Construction and Operation of Soaking Pits. II. The Effect of Heat Acceleration. Y. Yazawa et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 920–921). [In Japanese].—K. E. J.

Forging and Drop-Forging Furnaces. Conditions Governing Heating by Liquid and Gaseous Fuels. L. Bailly. (*Iron Steel Inst. Spec. Rep.*, 60, 1957, 37–40). Need for close control of temperature and atmosphere and means of achieving it are outlined. Insulation and the use of metallic recuperators improves the efficiency of intermittent furnaces and the effects on productivity and working conditions are discussed.

Application of Induction Heating to Forging Operations. J. Minssieux. (*Usine Nouvelle*, 1956, **12**, Oct. 4, 29–31). A review of installations in France.

Dual Frequencies Drop Induction Forging Costs. (*Iron Age*, 1956, **178**, Oct. 25, 116–118). The employment of induction heaters for billets, in automatic production lines forging

105-mm shells is described. 60-cycle preheater coils are used followed by 960-cycle coils.—D. L. C. P.

Forging Furnaces in Sweden. A. Roslund and E. Tholander. (*Metal Treatment and Drop Forging*, 1957, **24**, Feb., 47–53). Oil-fired and electric furnaces are compared. Furnace walls are shown and hearth shape considered, also pusher-type furnaces. Electric furnaces are then reviewed and labour and economic factors discussed.

On the Heating Property of a Forge Furnace with Recuperators. K. Morita et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 921–923). [In Japanese]. Comparison between furnaces with and without recuperators shows a steady reduction in fuel consumption in the former case for up to 9·3 h from firing. The relationship between inside wall temperature and the amount of heat stored in the walls as time progresses is illustrated.—K. E. J.

On the Decarburising and Scaling of Steel in the Heating Furnace. S. Komazuka et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 884–886). [In Japanese]. Results are given for the increase in weight by oxidation of samples (analyses given) of rimmed, semi-killed, killed, and low-chromium steels heated at 1200° C for times up to 5 h. Similar data are given for samples after various additions of aluminium.—K. E. J.

HEAT TREATMENT AND HEAT-TREATMENT FURNACES

The Commercial Heat-Treating Industry—1956. (*Steel Processing*, 1957, **43**, Jan., 18).

Current Heat-treatment Practice. R. J. Brown. (*Metal Treatment and Drop Forging*, 1956, **23**, Dec., 503–511). A general review of furnaces and processes is presented. Hardening, quenching, carburizing, carbonitriding, induction hardening, and salt bath treatment are outlined.

Steel Heat-Treating Highlights of 1956. C. L. Ipsen. (*Steel Processing*, 1957, **43**, Jan., 17, 51).

The Heat Treating Pilot Plant. H. Ross. (*Steel Processing*, 1956, **42**, Dec., 705–708). A general review of the functions of a laboratory heat-treating section, with typical results.

Modernization of Heat Treatment Shops in Czechoslovakia. O. Krásný. (*Czech. Heavy Ind.*, 1956, (1), 2–9). Radio-frequency heating is described and the characteristics of hardening machines are given. Monocarb case-hardening furnaces are described and the Škoda installations illustrated.

Automation in Heat Treatment of Small Parts. F. von Trotha. (*Indust. Heating*, 1956, **23**, Dec., 2556–2558). Austempering equipment is described.

Electric Heat Treatment Furnaces. J. B. Carroll. (*Elect. Rev.*, 1957, **160**, Jan. 11, 71–74). A general review is made of present-day designs and applications of electric heat-treatment furnaces for reheating, bright hardening, and malleablizing iron castings. It is suggested that both town's gas and electricity may be displaced in the future as heating media, at least in the larger installations, with bulk supplies of propane as a possible substitute.—L. D. H.

Heat Treatment With Artificial Atmospheres. O. Dorigo. (*Rivista Mecc.*, 1956, **7**, March 3, 31–35). [In Italian]. The author groups controlled atmospheres under two main headings: those which are protecting or reducing atmospheres and which have either no oxidizing or de-oxidizing effects and those which have a chemical effect and can make a metal absorb one or more elements. The various gases and the range of steels which they can help to produce are described. Details are also given of a controlled atmosphere furnace for the heat treatment of austenitic stainless steels.—M. D. J. B.

Effect of Controlled Atmospheres on Properties of Steel. N. Komuro et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 752–754). [In Japanese]. For SH 85 B and SAE 4320 steels (compositions given), the effects on impact values and hardness of the following atmospheres are discussed: vacuum, nitrogen, hydrogen, cracked ammonia, CO, CO–H_2, CO–CH_3OH, and CO–H_2–CH_4.—K. E. J.

Controlled Atmospheres in Heat Treating. C. W. Sanzenbacher. (*Iron Steel Eng.*, 1956, **33**, Nov., 71–76). The compositions of atmospheres for various purposes and apparatus for their production and control are reviewed.

Controlled Atmospheres for Heat Treatment. A. Adachi and S. Yamada. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1955, **5**, Oct., 419–423). Composition of gases from town's gas, propane, petrol and paraffin and their effects on hot steel were investigated. Factors in carburization control were studied.

The Safe Operation of Atmosphere Furnaces. J. Huebler (*Metal Progress*, 1956, **70**, Dec., 78–83; *Indust. Heating*, 1956 **23**, Dec., 2567–2568, 2570, 2572, 2574, 2576, 2578, 2580) Conditions for explosion, types of furnace, emergency pre cautions, and safety equipment are outlined.

Equilibrium Curves. Practical Application to Heat Treatments Carried Out in Controlled Atmosphere Furnaces. N. K. Koebel. (*Met. Ital.*, 1956, **48**, Oct., 447–455). [In Italian]. The author discusses the various reactions which take place between the steel and the constituent parts of the atmosphere in the furnace. Theoretical equilibrium curves are examined in detail and compared with equilibrium curves obtained by direct measurement. The use of the dew point as a means of checking furnace atmosphere is discussed. (7 references).

Instrumentation in the Heat-Treatment of Steel. I. The Nature of the Problem. W. F. Coxon. (*Metal Treatment and Drop Forging*, 1956, **23**, Dec., 499–502). Heat-treatment and pyrometry and atmosphere control are outlined. **II. The Importance of Instrumentation.** (1957, **24**, Jan., 7–10). Automatic control is briefly outlined and control factors summarized. Steady temperature, economic fuel usage and correct atmosphere maintenance are the factors stressed and the value of separate controls for all three is mentioned.

Furnace Television Equipment. (*Automation Ind.*, 1956, **3**, July, 155–156). Babcock and Wilcox equipment is described including the portable direct-viewing periscope.

Effect of Baking on Delayed Fracture of Electroplated Ultra High-Strength Steel. B. F. Brown. (*Naval Research Laboratory Report*, 4839, 1956, Oct. 3, pp. 18). Baking at 350° F after plating was examined by tests on notched tensile specimens. Relief was complete after 24 h for chromium plate, incomplete for Cd plate even after 200 h, and Zn plate showed little effect after 200 h.

Hardening Technology. W. Stuhlmann. (*Z.VdI.*, 1956, **98**, Aug. 21, 1486–1490). Developments in hardening techniques are surveyed, comprising gas carburizing, carbonitriding, induction and flame hardening, and salt bath treatment.

On the Local Hardening Phenomena of Wire Rods. I. Saito et al. (*Tetsu to Hagane*, 1956, **42**, 881–882). [In Japanese]. Microstructures of the rod in its normal condition, as locally hardened, after drawing, and after drawing and annealing are compared.—K. E. J.

Controlled Flame Hardening by Oxy-Town Gas. (*Gas World, Industrial and Commercial Gas Supplement*, 1957, **35**, Feb. 16, 44–46). An account of the apparatus and process of Peddinghaus (W. Germany).

Hardening and Tempering Steel Strip: Continuous Operation with Two Furnaces. (*Engineering*, 1957, **183**, Feb. 8, 170; *Gas World, Industrial and Commercial Gas Supplement*, 1957, **35**, Feb. 16, 46). An account of the installation of G. F. Homer (Redditch) Ltd., using town gas.

Quenching of Unalloyed Carbon-free Iron. G. V. Kurdyumov and M. D. Perkas. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **111**, (4), 818–820). [In Russian]. Almost carbon-free iron was subjected to tests of quenching from 1000° C and above in a 10% NaOH solution at 5° C. It is shown that both hardness and the width of X-ray lines vary with the initial temperature, while iron reheated in a high vacuum cannot be tempered at all. It is concluded that the tempering properties of carbon-free iron greatly depend on the internal structure of crystals, especially on the breakdown of the structure of γ-iron due to the γ–α transformation in the temperature interval of 1100°–1200° C, a range of initial temperature favouring the process of tempering.—S. I. T.

Studies on the Temperability of Carbon-steel Wire. On the Effect of Quenching Condition. S. Hara, Y. Miura, and M. Sugiyama. (*Nippon Kinzoku Gakkai-Si*, 1956, **20**, Jan., 1–5). [In Japanese]. Differences in temperability result from the difficulty of uniform dissolution of cementite in austenite; a spheroidal gives lower temperability than a lamellar structure. To equalize the toughness of pins, springs, etc., which are mass-produced, careful control of temperature and time of quenching is needed, and the initial structure must be homogenized.—K. E. J.

Changes in the Sizes of Carbide Crystallites on Tempering of Hardened Chromium Steel. Z. K. Kos'ko. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **108**, (6), 1072–1075). [In Russian]. Three samples of steel, after quenching and subsequent annealing at temperatures varying from 450° to 700° C, were

studied by means of X-rays for structural and particle size analysis. For steel with C 0·7%, Cr 3%, $(Fe,Cr)_3C$ is found at all temperatures of annealing, $(Cr,Fe)_7C_3$ only at high temperatures. For steel C 0·7%, Cr 8%, at high temperatures only $(Cr,Fe)_7C_3$ is present and at low temperatures $(Fe,Cr)_3C$ is present. Steel with C 0·7%, Cr 18% after quenching was found to be made of austenite. Only at 500° C $(Cr,Fe)_7C_3$ is found. At 600° C $(Cr,Fe)_{23}C_6$ is appearing, and becomes the sole carbide at 700° C. The size variation of carbide crystallites is discussed in detail. In all cases the formation of the new carbide phase leads to the diminution of the crystallites of the preceding phase.—S. I. T.

FORGING, STAMPING, DRAWING, AND PRESSING

Forging Technology. O. Kienzle and K. Lange. (*Z.VdI.*, 1956, **98**, Aug. 21, 1480–1482). Recent developments are surveyed with reference to 45 publications relating to plain tool and closed die forging, furnaces, forging equipment and tools, and wrought metals.—J. G. W.

Forging Industry Confident for '57. C. H. Smith Jun. (*Steel Processing*, 1957, **43**, Jan., 15).

Forging of Hollow Bodies. (*Usine Nouvelle*, 1956, **12**, Nov. 1, 93–94). A review of methods.

Drop-Forging in Tool Production. V. Zábransky. (*Czech. Heavy Ind.*, 1957, (1), 40–48). Production of various tools and the cold-pressing of prisms, dies, and cores are described.

Drop-Forging Dies and Tools. M. J. Husson. (*Metal Treatment and Drop Forging*, 1957, **24**, Feb., 61–64, 68). Both old and new hammers are discussed and die and tool design and die block production suited to either are considered. Costs, compositions, and durability are briefly referred to.

Steel for Drop Forging. H. J. Merchant. (*J. Australian Inst. Met.*, 1956, **1**, May, 33–40). Steel quality and the effects of surface and internal defects are briefly considered. Four grades of stock are described, the highest, for bars only, being absolutely free from surface defects. Seams, rokes, shell, and rolling overlaps, are described in regard to surface quality and pipe, secondary pipe, axial segregation, steel cleanness, and flakes to internal quality, with a short section on inherent quality, and conclusions. The defects are illustrated.

Forgeable Metals and Forging Design. (*Mat. Methods*, 1956, **43**, June, 161, 163). Carbon, alloy, and corrosion-, heat-resisting, and stainless steels, iron, and non-ferrous properties and notes on commercial practice. Tolerances of various kinds are tabulated for forgings up to 100 lb.

Rotary Furnaces Speed Shellmaking. (*Steel*, 1956, **139**, Oct. 22, 102–103). A plant which heats and forges billets and machines out 155 mm shells in 12 hours is described. Mechanical handling and rotary furnaces are features.

Guide to Hot Work Tooling. H. E. Replogle. (*Steel*, 1956, **139**, Sept. 24, 116–119). The care and use of hot forging, forming, extruding, and moulding dies are described. Tables give compositions, heat treatments, and hardnesses of tool steels developed for these applications.—D. L. C. P.

Working of Cast Iron by Hot Deformation. (*Usine Nouvelle*, 1956, **12**, Oct. 4, 23, 25, 27). Structure, speed, and temperature of deformation and the effects of alloying elements are reviewed. Methods and mechanical properties and uses are then considered.

Problems Connected with the Production and Ultrasonic Inspection of Heavy Upset Forgings. C. Roques, Ch. Dubois, and P. Bastien. (*Iron Steel Inst. Spec. Rep.* 60, 1957, 1–16). A frequent defect is found to be cracking associated with grain flow and located at equal distances from the surfaces in contact with the press dies. It is supposed that inclusions serve to initiate cracks and there is evidence of reduction in plasticity in the transverse direction. The risk of cracking would be greater where the diameter to height ratio is high. Ultrasonic inspection readily discloses these cracks, but does not distinguish them with certainty from elongated inclusions with similar distribution. Magnetic, metallographic, and other evidence is included and, in discussion, the significance of the defects disclosed is considered and the production of echoes from structural discontinuity. The difference between sulphide and silicate inclusion detection is also mentioned.

The Continuous Grain-Flow Process. P. Vérot. (*Iron Steel Inst. Spec. Rep.*, 60, 1957, 26–36). The Grain-Flow ("*fibrage intégral*") process has been applied to the forging of crank-shafts, to propeller hubs for aircraft and to the upsetting of coupling flanges on long shafts. The original ingots are carefully tested for defects which would give rise to cracks during upsetting. The process is described and illustrated and the forging press is shown.

Modern Die-Making Machines. Some Recent and Future Possibilities for the Drop-forging Industry. W. E. Golcher. (*Metal Treatment and Drop Forging*, 1956, **23**, Dec., 475–480).

The New Firminy Forging Shop of the Société des Ateliers et Forges de la Loire. G. Bois. (*Iron Steel Inst. Spec. Rep.*, 60, 1957, 71–77). An account with illustrations and plans of the shop which came into production in 1954. Ingots of maximum weight 12 tons can be forged. The press, hammers, and furnaces are also described. (Discussion, jointly with another paper, 83–85).

Unusual Press for Forging. (*Steel*, 1956, **139**, Sept. 3, 103). A 2000-t pull down forging press for the hot working of high alloy tool steels is described. It is single action, inverted type, working stroke 72 in.—D. L. C. P.

Doing More with Short Run Dies. (*Steel*, 1956, **139**, Sept. 3, 79–82). The use of dies which are cheaper to produce than permanent dies, for short and medium mass-production runs is considered. Sections deal with: steel rule dies, 'Magnetic' dies, plastic dies, preforming, template dies.—D. L. C. P.

Production for an Industry. K. T. Fulton. (*Aeroplane*, 1956, **91**, Dec. 7, 853–857). An account of production of aero-engines by Briggs Motor Bodies Ltd. Presswork, machining, and heat-treatment is described and illustrated. Control and costing are also mentioned.

A Review of the Heavy Press Program. J. Alico. (*Product Eng.*, 1956, **27**, Oct., 135–140). Installation of heavy forging and extruding presses under the U.S. Air Force programme are reviewed.

Mechanical Steel Tubing for Parts Fabrication. (*Mat. Methods*, 1956, **44**, July, 100–102). The economics of the utilization of tubing to replace bar stock in the production of steel parts is discussed. The reduction in machining costs warrants the use of tubing where large diameter, or deep holes are required, or where subsequent finishing operations are eliminated. Examples of typical applications show savings in costs of up to 25%.

The Safe Operation of Bar Reeling and Straightening Machines. (*British Iron and Steel Federation, Sub-Committee Report*, 1956, pp. 32).

Straightening by Heat Shrinking of Plates, Bars, Tubes and Sections. A. Heydacker. (*Rev. Gén. Méc.*, 1957, **41**, Feb., 49–52; Mar., 101–106; from *Revue l'Air Liquide*, 1956, Apr.). The process is described and numerous applications are illustrated in diagrams. The correction of distortions from heat-treatment, forming, and welding is shown. Local gas heating is used.

Hydraulic Stamp of Quality. R. Johnson. (*Steel*, 1956, **139**, Sept. 10, 144–145). The use of hydraulic presses by a maker of agricultural equipment, for forming, trimming, and piercing as well as deep drawing is described.—D. L. C. P.

The Metal Stamping Business To-day and Tomorrow. H. A. Daschner. (*Steel Processing*, 1957, **43**, Jan., 16).

Investigation of Punching Die Steel. I. The Effect of Carbon and Manganese on 6% Cr–Mn–W Steel Punching Dies. II. The Effect of Chromium, Tungsten and Nickel on 6% Cr–Mn–W Steel Punching Dies. S. Koshiba and T. Kuno. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Oct., 509–512; 512–515). [In Japanese]. I. The effects of 1·0–2·0% C and 0·6–1·4% Mn on steel containing 1·5% C, 1·0% Mn, 6% Cr, and 3% W were studied. As carbon and manganese contents increase, the self-hardening properties increase, the rate of deformation decreases, and the quenching temperature necessary for maximum hardness must be lowered. II. With the same steel, the self-hardening properties decrease as the Cr content (5–11%) and W content (0–6%) increase, but increase as the Ni content (0–1·5%) increases. The quenching temperature for maximum hardness is raised as the Cr and W contents increase and lowered as the Ni content increases. The rate of deformation is influenced by the quenching and tempering temperatures; the optimum contents of the elements are Cr 6–8%, W 1·5–2·0%, and Ni 0–0·6%.—K. E. J.

The Extrusion of Steel with Glass Lubricant. S. Sejournet. (*Rev. Mét.*, 1956, **53**, Dec., 897–914). Formulæ are derived for the calculation of forces occurring during the extrusion operation and friction coefficients. The part played by the glass during the actual extrusion is discussed. The difference in flow pattern of metal during an extrusion operation with

and without glass is described and illustrates the properties of the extruded products and the economical advantages of the technique. Details are given of the equipment used for extrusion, their production capacity, and the world-wide applications of the process.—B. G. B.

Properties and Possibilities of Use of Parts from Steel Extruded in the Cold. F. Feldmann. (*Mem. Soc. Ing. Civils France*, 1956, **109**, July-Aug., 247–261). Examples are given of the type and shape of steel objects which can be successfully cold extruded and of factors which govern extrusion.—B. G. B.

The Steel Tube Industry. L. Tourtoulou. (*Arts et Manuf.*, 1957, Jan., 44–45). A general account of the industry in France.

Surface Defects in Steel Tubing. R. S. Thomas. (*J. Australian Inst. Met.*, 1956, **1**, May, 26–33). Typical defects are reviewed with reference to the uses of the tubes and the effects on them of surface imperfections. Seams, overlaps and slivers, surface cracking, defects in continuous weld tubing and in galvanizing, and corrosion effects are briefly discussed.

ROLLING-MILL PRACTICE

A Slip Line Field for the Hot Rolling Process. J. M. Alexander. (*Proc. Inst. Mech. Eng.*, 1955, **169**, (50), 1021–1030). A geometrical representation due to Prager is used to solve the hot-rolling problem. It is assumed that yield stress is constant throughout the plastic zone and that shear stress along the roll-material boundary attains the yield shear stress of the material.

Contributions to the Study of Rolling Mill Installations. G. Grenier. (*Echo Mines*, 1957, Jan., 26–30). A continuation of the series. This section continues with the malleability and flow of metal in cold-rolling. Rolling between smooth rollers, reduction of bars of varying thickness, and the case of rollers of different diameters are considered.

Alloy Steels. Practice at the Clyde Alloy Steel Co. Ltd. (*Iron Coal Trades Rev.*, 1957, **174**, Jan. 18, 139–144). A review of electric melting and rolling methods, with notes on research and development, is given.

Effects of Screw and Speed-Setting Changes on Gauge Speed and Tension in Tandem Mills. W. C. F. Hessenberg and W. N. Jenkins. (*Proc. Inst. Mech. Eng.*, 1955, **169**, (52), 1051–1062). As the volume of metal passing through each stand in a given time is constant, changes in setting or speed in one stand must be taken up by the resilience of the others. An attempt is made to relate the changes due to such a change in interstand tension and finishing gauge to the electrical and mechanical characteristics of the mill and to predict tandem mill behaviour.

Power Requirements of Rolling Mills. J. H. Taylor. (*Iron Steel Eng.*, 1956, **33**, Oct., 55–66). Bases of calculation are given and curves for various conditions. Slabbing, hot strip, tandem cold strip, reversing, and temper mills are all considered.

Distribution of Power in a Modern Cold Mill. E. A. Young. (*Iron Steel Eng.*, 1956, **33**, Dec., 82–88). Youngstown Sheet and Tube Co. Indiana Harbor works underground system with pump type rectifiers is described.

Gear Tooth Forms for Steel Mills. J. J. Stolz. (*Iron Steel Eng.*, 1956, **33**, Oct., 112–121).

Experimental Formula for the Rolling Pressure in Cold Rolling. N. Shigemoto et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 820–821). [In Japanese]. Parameters for a formula under consideration are established for 18–8 stainless and SK 5 steel.—K. E. J.

Measurement of the Mean Specific Roll Pressure and Spread of Stainless Steels in Hot Rolling. S. Yamane et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 938–940). [In Japanese]. Results of measurements from a mill are given for carbon, 18–8 and 18Cr steel.—K. E. J.

Measurement of Force on a Hot Wide-Strip Mill. W. Lueg and H. G. Müller. (*Stahl u. Eisen*, 1956, **76**, Sept. 20, 1246–1248). Force and torque measurements on the first stand of a continuous finishing line were made to determine the distribution of load between parts of the transmission. Fluctuations in load on the work rolls were attributed to small variations in roll diameter, and also to temperature differences between the upper and lower sides of the strip.

Converted Lathe Builds Up Worn Rolls. R. Hall. (*Iron Steel Eng.*, 1956, **33**, Nov., 148). Arc welding practice using an old long lathe bed is briefly described.

Modernization of 44-in. Blooming Mill at J & L's Aliquippa Works. A. B. Millman. (*Iron Steel Eng.*, 1956, **33**, Oct., 103–108). Electrification is described.

Roughing Sequences by Flattening Passes, Successive Quartering and Upsetting Passes. A. Petitfrère. (*Centre Doc. Sidér. Circ. Inf. Tech.*, 1956, **13**, (11), 2237–2252). French rolling practice is discussed with particular reference to American practice. Methods of ingot reduction are considered in detail.—B. G. B.

Effect of the Rolling Formula on the Properties of Wire Rods. N. Eguchi et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 940–942). [In Japanese].—K. E. J.

Hot Rolling by Drag Roll in Continuous Wire Rod Mill. T. Harada et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 936–938). [In Japanese]. Curves are given for reduction against forward slip of the roll stand with the pinion stand, and of the roll stand with the drag roll.—K. E. J.

The Modern 4-Strand High-Speed Continuous Wire Rod Mill at Hikari Works. S. Dazai. (*Tetsu to Hagane*, 1956, **42**, Sept., 935–936). [In Japanese].—K. E. J.

Effect of Finishing Temperatures on Properties of Hot Rolled Steel Plate. R. H. Frazier, F. W. Boulger, and C. H. Lorig. (*Iron Steel Eng.*, 1956, **33**, Oct., 67–79). Resistance to brittle fracture can be increased by lowering final rolling temperatures. This produces smaller ferrite grains and raises yield strength. Ultimate strength and elongation are unaffected.

A Mill for Cold Rolling Metals to Close Tolerances. M. G. Sendzimir and L. Zdanowicz. (*Iron Steel Eng.*, 1956, **33**, Nov., 65–70). The development of the Sendzimir Mill is outlined and its uses reviewed.

New Skelp Mill Reflects Steel Industry's Growth. (*Castings*, 1956, **2**, Nov., 17, 19, 21). An account of an 18-in. mill erected at Newcastle Steel Works, Australia, with nine horizontal stands and a maximum finishing speed of 2000 ft/min with five vertical edging mills.

Rolling of Thin Strip. Part II. M. D. Stone. (*Iron Steel Eng.*, 1956, **33**, Dec., 55–76). Prediction of mill pressures and power required is treated mathematically and data given in tables and graphs for use in design. Part I was published in 1953.

Rolling Mills for Thin Strip. J. Porché. (*Arts et Manuf.*, 1957, Jan., 41–43). A review of French installations with statistics.

Study on the Spheroidizing of Cementite in Hot Rolled Strip. I. Matsuo et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 758–759). [In Japanese]. The effect of vibration when spheroidizing by heating below the Ac_1 temperature, viz. at 680°, 700°, and 720° C, generally improves the results, particularly for heating times of 60–120 min. Similar results obtain for spheroidizing by slow cooling through the Ac_1 temperature from 740–770° C, particularly for carbon contents above 0·80%.—K. E. J.

On Residual Stresses in Mild-steel Sheets for Tinplate. I. R. Iwamoto. (*Tetsu to Hagane*, 1956, **42**, Sept., 821–822). [In Japanese]. The distribution of stress between centre and surface is investigated for temper-rolled and roller-levelled mild steel strip.—K. E. J.

Circular Annealed Controlled Gauge Cold Rolled Strip. (*Western Metals*, 1956, **14**, Aug., 54–56). Details are given of the recently established Cold Metals Products Co.'s strip mill at Los Angeles. The mill is a single stand CMP reversing unit rolling 8-in. wide alloy and carbon steel strip at speeds up to 2000 f.p.m. in gauges from 0·001 in. to 0·125 in. The rotary annealing furnace permits coils to be annealed in an inert atmosphere under precise temperature control.

Some Effects of Lubricants in Cold Rolling Thin Strip. J. C. Whetzel Jun. and C. Wyle. (*Metal Progress*, 1956, **70**, Dec., 73–76). Results of tests carried out on the cold rolling of strip with a variety of lubricants are described and show that the maximum reduction of thin strip can be increased from approximately 12% to 62% at the same rolling speed by changing the lubricant.—B. G. B.

How Temperature Affects Strip. E. L. Robinson and D. J. Goettge. (*Steel*, 1956, **139**, Oct. 1, 164–166). The finishing and coiling temperatures of steel strip are considered in relation to their influence on the properties of the product (e.g. grain structure and hardness).—D. L. C. P.

Velindre Steel-strip Mill. Magnetic Amplifiers used for Automatic Speed Control. (*Beama J.*, 1957, **64**, Feb., 10–12).

Automation in Cold Rolling. M. Reimann. (*Stahl u. Eisen*, 1956, **76**, Dec. 13, 1665–1668). The realization of automation of the cold-rolling process of strip shows some difficulty as

cross-section and shape of the strip are affected by many factors, such as structure, hardness, and surface quality. The author describes a pneumatic strip tension control system for a d.c. driven, reversing, four-high, cold finishing mill with work rolls of 280 mm dia. and rolling speeds of up to 200 m per min and an automatic gauge control device. This device changes only the roll gap and does not affect roll speed of strip tension. The gauge control keeps a strip of 340 × 0·6 mm well within the permissible tolerance of ± 0·04 mm even during acceleration and deceleration.—T. G.

Automation of a Reversing 12-Roll Rohn-Type Cold-Rolling Mill. H. Schmale. (*Stahl u. Eisen*, 1956, **76**, Dec. 13, 1698–1700). The author describes a reversing stand for rolling strip 60–135 mm wide and gauges from 0·08 to 1·50 mm. (Usually below 0·4 mm). Diameter of the work rolls is 35 mm, drive rolls 70 mm and backing rolls 150 mm. Max. rolling pressure is 22 t, max. rolling speed 180 m/min. The gauge is automatically controlled by an "Emicron" device working on the transformer principle. Diagrams show the superiority of the automatic gauge control compared with hand control. The author deals, however, mainly with economic aspects.

Calculations of the Pilger Cold-Rolling Process. F. W. Neumann. (*Stahl u. Eisen*, 1956, **76**, Dec. 13, 1704–1705). The author disputes the validity of some of the formulæ which Geleji put forward (*Acta Techn.*, 1955, **11**, 461) and gives the correct solutions, e.g. for rolling force, power required, reduction of wall and diameter and total reduction, and feed.—T. G.

Cold Rolled Carbon Spring Steel. (*Amer. Iron Steel Inst. Steel Prod. Man.*, 1957, Jan., pp. 36).

The Use of Cold Rolling for Finishing Shafts and Bores. H. König. (*Eng. Digest*, 1956, **17**, Oct., 433–436; from *Werkstattstechnik u. Maschinenbau*, 1956, **46**, June, 274–282). Rolling and attachments to machine tools are discussed.

The Effect of Cold Rolling and Annealing on the Mechanical Properties of Cold Rolled Stainless Strip and its Structure. K. Fukuda et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 827–829). [In Japanese]. The steel contained 14·74% Cr and 0·18% Ni, and the cold-rolling schedule is explained. As reduction increased from 0 to 70%, hardness increased smoothly to a constant value of 270 Vickers, tensile strength increased more sharply to 86 kg/mm², and elongation fell very sharply to a constant value of 2%. With annealing at 400° and 550° C, the hardness curves were similar to that described, but annealing at 600° and 800° C caused a fall in hardness with increasing reduction.—K. E. J.

Uses of Mathematical-Statistical Methods in the [Iron and Steel] Industry. K. Brücker-Steinkuhl. (*Forsch. Wirts. Nordrhein-Westfalen*, 1956, No. 288, pp. 103). Applications to cold strip mill rolling, grinding processes, control of fabrication processes, and uses of the analysis of variations are illustrated with examples. (33 references).

Quality Control in a Pipe Mill. J. A. Curry. (*Steel*, 1956, **139**, Sept. 10, 148–156). The use of statistical methods in a welded-pipe mill to increase production and show sources of trouble is described. Check is kept on the following: average outside diameter, out-of-roundness, forming and weld defects, straightener performance, and threader adjustment.—D. L. C. P.

Electric Rolling Mill Drives. J. Soukeník. (*Czech. Heavy Ind.*, 1956, (8), 3–15). An illustrated account of installations at the Škoda works.

Works Experience with the Main Electric Drive on New Reversing Mills. K. Giesdorf. (*Stahl u. Eisen*, 1956, **76**, Sept. 20, 1231–1246). The author compares Ilgner with rectifier supply and considers the suitability of each method for the purposes of the drive. He discusses bus bars, switching arrangements, power consumption, works experiences and difficulties, and the effect of plant characteristics and mode of operation on reaction.

Electric Drive Systems for Rod, Bar and Merchant Mills. F. E. Fairman and A. C. Parsons. (*Iron Steel Eng.*, 1956, **33**, Oct., 80–86). Choice of control systems and prediction of performance are discussed.

Friction of Steel Slabs on a Roller Table under Varying Physical Conditions. S. K. Dean and M. A. Kilburn. (*Proc. Inst. Mech. Eng.*, 1955, **169**, (54), 1081–1089). Tests were carried out on a model table. When cold the effective coefficient of friction was greater with a light than with a heavy slab and greater at low roller speeds than at high. It was independent of temperature between 700–1100° C and was less sensitive to weight and speed while hot. When slip was small the coefficient decreased with cold and increased with hot slabs (mean values 0·20 and 0·29); grit-blasting and heavy scaling or addition of wet powdered mill scale increased the value. Steelworks observations confirmed the findings.

Feeding Billets to Continuous Mills. (*Iron Steel*, 1957, **30**, Feb., 60). A drum-type switch devised by Schloemann A.G. for guiding several strands to the mill is described.

Some Special Types of Rolling Mill Cranes. Foundry Beam, Claw and Polyp Cranes. V. Vaverka. (*Czech. Heavy Ind.*, 1956, (5), 17–22). An illustrated account of the design, capacity, and other characteristics of recent installations.

Faster Inspection in a Rod Mill. (*Steel*, 1956, **139**, Sept. 3, 78). An installation is described for the semiautomatic, magnetic inspection of steel rod samples for surface defects.

Defects in Steel Sheets. R. A. Parker. (*J. Australian Inst. Met.*, 1956, **1**, May, 18–26). Hot-rolled black sheets are considered and the paper is descriptive rather than a discussion of causes and remedies. Blisters, pipe, seams, cat scratches, spall marks, tail marks, jumped and pinched sheets, and scale are dealt with.

Surface Defects in Steel Products Produced by Rolling Mill Operations. E. J. Buckman. (*J. Australian Inst. Met.*, 1956, **I**, May, 7–17). Defects in rolled products are classified and defined, 22 in all. These comprise seams, hot shortness, blisters, burnt steel, edge cracking, lamination, pipe, scabs and scrap, splits or cracks in billets or blooms, and snakes, which are classed as metallurgical defects, deseaming cracks and scarfing fins which are reconditioning defects, brickmark or ganister, camber, fins or overfills, laps, pitting, ripple, roll marks, scratches, and slivers, which are classed as operational defects.

Five Inch Automatic Shear. (*Brit. Steelmaker*, 1957, **23**, Mar., 82–84). A machine for feeding and cutting billets up to 5 in² at a rate of 14 cuts/min, quite automatically, is described.

Cold Billet Shear. (*Iron Steel*, 1957, **30**, Mar., 113). See previous abstract.

MACHINERY FOR IRON AND STEEL PLANT

Electric Overhead Travelling Cranes. The Present-day Trend towards Smaller and Lighter Heavy-duty Cranes. J. M. Beskine. (*Mech. Handling*, 1956, **43**, Oct., 638–643; Nov., 683–692; Dec., 741–749; 1957, **44**, Jan., 33–39; Apr., 229–232). Steelworks requirements are considered and the work of BISRA described. Specifications and tests are then given. The paper arises mainly out of the 1955 Harrogate conference. Design, maintenance, and standardization are discussed. Controls and "ergonomics" with discussion of control problems and design from the anthropometric standpoint, cab lay-out, drives, and performance are reviewed. Experimental work in hand at BISRA is then outlined. (36 references).

Design Principles for Crane Bridges. K. Eckinger. (*Stahl u. Eisen*, 1957, **77**, Jan. 10, 15–23; discussion, 29–32). The author compares German and American design principles for iron and steel works cranes and discusses the various types of construction from the static and dynamic point of view. He quotes model tests on box girders and stresses their merit, particularly the multiple-cell box type.—T. G.

Torsion-Proof Box Girders for Cranes in Iron and Steel Works. H. Schwarz. (*Stahl u. Eisen*, 1957, **77**, Jan. 10, 24–32). The author discusses in detail the merits of torsion-proof box girders for cranes used in iron and steel works and gives static calculations of the deflections under load. The deflections of a box girder may be larger than those of a conventional girder although the stresses in the latter may be very much higher than those in the box girder. The author quotes the advantages of the torsion-proof box-type girder, which are also stressed in the discussion.—T. G.

On the Standardization of Drives and Gears of Iron and Steel Work Cranes. A. Wolf. (*Stahl u. Eisen*, 1957, **77**, Jan. 10, 33–36). The author discusses the standardization of drives and gears of cranes in iron and steel works.—T. G.

The Application of Multiple Drives for the Travelling Gear in Cranes in Steel Works. W. Theuser. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1464–1470). The use of twin motors is advantageous in cranes of small track and long wheel base, whereas four motors should be used in cranes of wide track and short wheel base. The latest trend is to have single-wheel drive without linking the wheels mechanically. In some cases the

four motors are employed only for the initial acceleration, further travel being effected by the traction motors alone. Single wheel drive, it is claimed, has many advantages, such as reduction in types of motor, shorter repair times, better power factors, and reduced accident hazard.—T. G.

Modern Three-Phase Alternating Current Controls for Intermittent Operation, Particularly of Cranes, in Iron and Steel Works. H. Enke. (*Stahl u. Eisen*, 1956, **76**, Nov. 15, 1564–1569). The author deals with automatic counter-current braking, including a time-relay for reversing in travelling. Similar automatic controls are described for the lifting gear as well as a remote control for both travelling and lifting.

Steel Structures in the Building of Ironworks and Mining Machinery in Czechoslovakia. G. Novotny. (*Acier Stahl Steel*, 1956, **21**, Dec., 493–498). [In English]. This article describes a number of welded structures in ironworks and pit-head gear. In addition to the more attractive appearance, welding has resulted in a saving of material.—M. D. J. B.

Developments in Steam Generating Units for Steel Plants. F. X. Gilg and N. W. Young. (*Iron Steel Eng.*, 1956, **33**, Oct., 94–102). Gaseous and solid fuels and recent trends in design are reviewed.

LUBRICATION

Application of Oil Mist Lubrication in the Steel Industry. T. M. Murphy. (*Iron Steel Eng.*, 1956, **33**, Dec., 77–81).

Additives in Steel Mill Lubricants. M. S. Clark. (*Iron Steel Eng.*, 1956, **33**, Oct., 87–93). Additives are classified according to purpose and materials and properties are discussed.

Some Aspects of Coke Works Lubrication. N. Errington. (*Gas World, Coking Section*, 1957, **50**, Mar. 2, 49–52, Discussion, 53). Gears and bearings are dealt with, special steels and anti-friction metals being considered.

Lubricants of Tomorrow. (*Steel*, 1956, **139**, Aug. 27, 80–82). The fields of application of various types of lubricants are noted and future trends in their development considered. Improvement of multipurpose oils and greases is important. Synthetic materials (e.g. silicones) are particularly useful in extreme conditions.—D. L. C. P.

Simulated Gear Tooth Contacts: Some Experiments upon their Lubrication and Subsurface Deformation. A. W. Crook. (*Chartered Mech. Eng.*, 1956, **3**, Oct., 416–418). The author describes simulative experiments on a disc-testing machine. The results indicate that the temperature of the engaging surfaces influences the lubricant film and that plastic deformation occurs only in a subsurface layer of the disc.—A. W. McC.

WELDING AND FLAME CUTTING

Welding and Cutting. A. Matting. (*Z.VdI.*, 1956, **98**, Aug. 21, 1482–1485). This is a survey of the year's developments in welding and flame cutting technology. The topics discussed include welding techniques and materials, stress relief, flame cutting techniques, equipment, and testing methods. (46 references).—J. G. W.

The Development of the Science and Technique of Arc Welding in the U.S.S.R. N. N. Rykalin. (*Sheet Metal Ind.*, 1957, **34**, Jan., 35–40). With discussion.

Welding Technology in the Soviet Union. W. Anders. (*Technik*, 1956, **11**, Nov., 761–766). The report of a study group from the East German Republic is summarized. Principal topics are automatic, electro-slag, argon-arc, carbon dioxide, and electric resistance welding.—J. G. W.

The Oxy-Acetylene Flame in Steel Mill Maintenance. P. Koval. (*International Acetylene Association Proc.*, 195, 1–55, 1956, 349–355). Fabrication and repair jobs are briefly catalogued.

New Fields of Application of CO_2. (*Schweisstechn.*, 1956, **10**, Sept., 121–122). The use of carbon dioxide as a shield in the carbomatic welding, or carboflux methods, is discussed.—U. E.

Correct Hard Welding. S. Lundin. (*Svetsaren*, 1956, **21**, (4), 63–72). [In Swedish]. After discussing at length the correct conditions to be observed in order to ensure the production of satisfactory hard welds, the article goes on to comment on the best methods of dealing with numbers (24 in all) of fractured castings belonging to industrial machinery of all types.—F. R. H.

The Development of Suitable Electrodes for the Welding of Cast Iron. R. Cox. (*New Zealand Eng.*, 1956, **11**, Oct., 345–348). Nickel or nickel-iron core wire electrodes have been found to be satisfactory. Structures are illustrated.

New Iron-Powder Electrodes and their Applications. R. Shutt. (*Welding J.*, 1956, **35**, Dec., 1207–1213). Different types of iron-powder electrodes are described. Illustrations are given of their application to welding structural steel, gears, and car bodies.—U. E.

Welding with Stainless Bi-metallic Blocks. A. Franzen. (*Svetsaren*, 1956, **21**, (3), 49–54). [In Swedish]. This article concerns the use steel blocks faced with acid-resistant and other metals—nickel, Monel, Inconel also copper, aluminium, silver, and titanium—for effecting welded repairs of industrial chemical apparatus. The blocks can be supplied in several thicknesses with varied proportions of corrosion-resistant material ranging from 10–20%. Good tensile properties are claimed for the blocks and numerous illustrations appear in the text showing the method of preparing the welded repairs.

Tube Welding. C. Losito. (*Rivista Mecc.*, 1956, **7**, July 7, 7–12; July 21, 13–20; Aug. 4, 35–41). [In Italian]. A comprehensive review is given of all aspects of tube welding. Oxy-acetylene and arc welding are discussed; working conditions, electrodes, the preparation of welding surfaces and other materials used in welding are also considered. Finally the author discusses the behaviour of the metal in the neighbourhood of the weld. (11 references).—M. D. J. B.

High Frequency Continuous Seam Welding of Ferrous and Nonferrous Tubing. H. B. Osborn Jun. (*Welding J.*, 1956, **35**, Dec., 1199–1206). The application of high frequency (well above 60 cycles) electrical energy to the continuous electrical seam welding of tubing is described.—U. E.

Welding of Steel with Consumable Electrodes under a Shield of Carbon Dioxide. E. Sellier. (*Acier Stahl Steel*, 1956, **21**, Dec., 489–492). [In English]. The author describes the shielded carbon-arc method of welding steel and gives a summary of test results and an outline of the plant employed in carrying out these tests.—M. D. J. B.

Positioners in Arc Welding Processes. O. Grossi. (*Acciaio Costruzioni Met.*, 1956, **8**, Jan.-Feb., 9–16). [In Italian]. The author describes the use of jigs and positioners in the welding of large parts. A number of examples are given and handling and welding procedures discussed.—M. D. J. B.

Automatic Submerged Arc Welding Installations for Reconditioning Parts. O. Grossi. (*Ing. Mecc.*, 1956, **5**, Nov., 55–63). [In Italian]. The author describes welding techniques for the reconditioning of worn machine parts, rail-wheel tyres, and mill rolls.—M. D. J. B.

Stainless Steel Fabricated by Automatic Welding Process. (*Australian Mach. Prod. Eng.*, 1959, **9**, Sept., 60–61). Emergency gates for 84 in water outlets as constructed by Byrne and Davidson Pty. Ltd. are described.

Welding Precipitation-Hardening Stainless Steels. G. E. Linnert. (*Welding J.*, 1957, **36**, Jan., 9–27). The fourteenth Adams Lecture covers the metallurgical structure and properties of the four major types of precipitation-hardening stainless steels and presents details on their weldability, heat treatment, and welding procedures.—U. E.

New Developments in the Metallurgical Field when Welding Iron and Steel. K. L. Zeyen. (*Schweisstechn.*, 1956, **10**, Nov., 141–143). A brief review is given of published data on the effect of electrode ingredients on the weld quality, and the influence of novel welding methods such as the argonaut process, sigma process, and the use of CO_2 instead of argon or helium.—U. E.

Rules for Welding TOR-Steel. S. Soretz. (*Schweisstechn.*, 1956, **10**, Oct., 125–130). TOR-steel is a strain-hardened structural steel used for reinforcing concrete. Suitable welding techniques and rules for obtaining satisfactory joints and properties are discussed.—U. E.

Time–Temperature Dependence of Austenitic Stainless Steel Welded Joint Components. J. Heuschkel. (*Welding J.*, 1956, **35**, Dec., 569s–581s). An investigation was made of the time–temperature dependence of austenitic stainless steel welded joints. The author enumerates the phenomena involved and a series of corrective procedures are suggested.—U. E.

Inhibition of Martensite Formation in Electric Arc Welding. F. Dechner and H. Speich. (*Stahl u. Eisen*, 1956, **76**, Sept. 20, 1249–1251). The authors discuss electric arc welding of 6–15 mm plate to various specifications. Attempts were made to inhibit martensite formation in the weld and in the heated zone by causing a suitable burner to follow the electrode at a set distance.

Coating Ingredients' Influence on Surface Tension, Arc Stability and Bead Shape. T. H. Hazlett. (*Welding J.*, 1957,

36, Jan., 18s–22s). A study of the effect of individual coating ingredients on the quality of the final weld deposit is described.

Argon–Hydrogen Shielding-Gas Mixtures for Tungsten-Arc Welding. Y. McElrath and E. F. Gorman. (*Welding J.*, 1957, **36**, Jan., 28–35). The use of argon–hydrogen shielding gas for welding various grades of stainless steel is discussed. A smooth, clean weld is obtained, a more fluid puddle, longer electrode life, and faster weld speeds can be achieved than with argon or helium.—U. E.

Effect of the Tip Temperature on the Gas Ratio of Oxy-Acetylene Flames in the Low Pressure Type Welding Torch. I. Onishi and M. Mizuno. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1955, **5**, Oct., 453–467).

Repairing Castings from Coast to Coast. W. H. Lane. (*International Acetylene Association, Proc.* 1951–55, 1956, 412–415, Discussion, 415–421). The work of Midwest Casting Repair is described. Deep V cast iron preparation and preheat before braze-welding have been eliminated, and normal crack welding practice has been modified.

Fabrication of a Welded Steel Crankcase for a Large 2-Cycle Diesel or Natural Gas Engine. L. L. Young. (*Gen. Motors Eng. J.*, 1956, **3**, (4), 22–27). An illustrated account is given of the development of a welded crankcase for a large radial Diesel engine. The fabrication of each of the 4-cylinder ring sub-assemblies is described, also the machining operations carried out, and the procedure for the final assembly of the 9-ft long complete crankcase.—E. A. C.

Properties of Austenitic Chromium–Manganese Stainless Steel Weld Metal. W. T. DeLong and H. T. Reid Jun. (*Welding J.*, 1957, Jan., 41s–48s). The study covers the ductility of welded alloys in the range 0·10–0·90% C, 7–18% Mn, 0–21% Cr, 0–4% Ni, and the effect of other alloy additions on the strength and ductility. A comparison is made of the mechanical properties of several of the more promising alloys with conventional chromium–nickel types.—U. E.

Flame-Plating for Wear-Resistance. (*Product Eng.*, 1956, **27**, Sept., 202–205). Tungsten carbide and alumina coating by the Linde Air Products Co. process is described and the properties of the materials given.

Melting and Bonding of Composite Metals Utilizes Special Metallurgical Processes. (*Indust. Heating*, 1956, **23**, Dec., 2538–2540, 2542, 2544, 2546, 2548, 2550, 2552). Bimetallic strips, including Al, Cu, and Ni on steel, are made by Metals and Controls Corp. Processes are described.

Non-Destructive Testing of Welds. H. Anders. (*Schweisstechn.*, 1956, **10**, Nov., 144–145). The advantages of using X-rays, the betatron, γ-rays, ultrasonic test methods or magnetic equipment for testing welds, are briefly discussed.

Ultrasonic Testing of Welds in Thin Sheet. K. Wellinger and S. Scharschmidt. (*Schweissen u. Schneiden*, 1956, **8**, Dec., 469–476). The application of ultrasonic testing to automatic seam welded thin sheet was investigated. It was found that the ultrasonic test method showed up faulty welds but could not distinguish between medium and good weld seams. Lack of penetration in butt welds was not detected clearly, though faults inside the weld were observed. The "impulse-echo" method gave better results detecting faults in a 3 mm thick welded sheet with subsequent failure. The ultrasonic test method is recommended for weld seams where the root cannot be examined visually.—U. E.

Pipe Line Butt-Weld Inspection by Ultrasonic Methods. W. Lloyd-Ellis. (*Gas World*, 1957, **145**, Jan. 12, 134–135).

Radiographic Testing of Welds and the Quantitative Evaluation of Faults Revealed by Radiography. Porous Welds Caused by Wet Electrodes. M. Robba. (*Ing. Mecc.*, 1956, **5**, Aug., 33–39; Oct., 43–48; Nov., 47–51). [In Italian]. The author reviews specifications for the radiographic testing of welds and examines the possibility of evaluating quantitatively the faults shown up by the X-ray photographs. A series of tests carried out on porous welds is described, the porosity being due to wet electrodes. A quantitative relationship is established between the incidence and magnitude of defects and the percentage loss in strength of the welds. (15 references).—M. D. J. B.

How To Braze Stainless. H. M. Webber. (*Steel*, 1956, **139**, Sept. 3, 94–100; Sept. 10, 158–162). Part I describes techniques for dealing with the difficulties encountered in brazing stainless steels, and how to cope with awkward constituents like Si, Ti, and Al. Part 2 covers brazing equipment, time–temperature cycles, and atmospheres for brazing.—D. L. C. P.

Dip Brazed Parts Take the Heat. (*Steel*, 1956, **139**, Oct. 8, 114–115). Processes developed for the brazing of stainless and low-carbon steel and Inconel assemblies, so that they will withstand temperatures up to 1500° F are described. Filler metals are copper, nickel–chrome, nickel–silicon, and silver–manganese. Corrosion resistance, hardness, and tensile values remained high.—D. L. C. P.

Brazing Titanium to Titanium and to Mild and Stainless Steels. W. J. Lewis et al. (PB 111434, 1955; *TIDU List* 596, pp. 57). Shear strength tests are reported and heating by induction and by oxyacetylene torch are compared. Pre-coating experiments are described with other elements.

Cutting in a Steel Mill. R. Kopecky. (*International Acetylene Association Proc.*, 1951–55, 1956, 563–571). Heavy plate cutting, "stack" cutting of blanks for tank heads, scrap preparation, O.H. furnace spills and other processes are described using oxy-acetylene torches.

Cutting Problems. (*Brit. Steelmaker*, 1957, **23**, Mar., 88). A note on new gas cutting installations.

How Cutting Helps to Speed Modern Steel Fabrication. J. N. Meyer. (*International Acetylene Association Proc.*, 1951–55, 1956, 556–562). Oxy-acetylene cutting of structural steel is described.

Recent Developments in Powder Processes. R. S. Babcock. (*International Acetylene Association, Proc.*, 1951–1955, New York 1956, 275–281). The cutting of stainless steels and other alloys by the process is briefly reviewed.

Refinery Equipment Requires Quality Oxy-Acetylene Cuts for Weld Preparation. C. B. Robinson. (*Western Metals*, 1956, **14**, July, 52–54). The importance of cutting and edge preparation prior to welding is described. The criteria of a satisfactory cut are discussed and the factors which affect the edge quality are listed. Several commonly occurring cutting faults are analysed and the reason for their occurrence is given.—A. W. MCC.

In Search of Perfection. (*Torch*, 1956, Autumn, 6–9). An account of oxy-gas cutter blowpipes is given.

MACHINING AND MACHINABILITY

Study of High Speed Machining (V). Fundamental Study Based upon Tool-Chip Contact Area. H. Takeyama and E. Usui. (*J. Mech. Lab.*, 1956, **10**, Sept., 167–177). Setting aside empirical equations a universal formula is derived by study of the actual mechanism of metal cutting. The controlling factor is the contact area or stress concentration at the cutting edge.

Measurements of the Compression of Turning Chips and Observations of Tool Flank Surface Wear in Fine Turning with Carbide Tools. W. Leyensetter. (*Z.VdI.*, 1956, **98**, June 21, 957–996). Investigations of fine turning with carbide tools are reported, the results of which establish a dependence of the degree of compression of turning chips on small structural differences in the workpiece. This compression is also affected by tool wear.—J. G. W.

Cooling and Lubrication in Metal Cutting. W. Reichel. (*Z.VdI.*, 1956, **98**, June 21, 963–970). Following an outline of the fundamentals of dry and wet cutting, compositions of cutting fluids are surveyed, reference is made to oil mist lubrication, to cooling by cold gases and the use of refrigerated fluids. The article is concluded by a discussion of measurements of cooling and lubricant performance and of examples of application. (35 references).—J. G. W.

Lubrication and Cooling in Machine Tool Operation. D. Nunes Vais and M. Gorini. (*Ingegneria Mecc.*, 1956, **5**, Dec., 49–54). [In Italian]. The authors show the increasing need for thorough lubrication and better coolants as the drive for productivity grows and automation develops. A comprehensive review of lubricants and cutting oils is given and the benefits which can be derived from planned servicing and maintenance are stressed. A useful bibliography is given with 34 references to works on lubrication and 27 references to cutting fluids.—M. D. J. B.

Milling High-Tensile Steel. L. G. Burnard. (*Aircraft Prod.*, 1956, **18**, Sept., 351–353). Cutters with special thread-form serrated cutting edges are used.

Milling with Tungsten Carbide Tools. O. Wiederkehr. (*Australian Mach. Prod. Eng.*, 1956, **9**, Sept., 55–59).

Carbide Tooling. (*Aircraft Prod.*, 1956, **18**, Nov., 474–478). Application to steel-bar machining and the use of wide-face form tools on steel bar operations are described.

The Grinding of Steel Tools. G. Evrard. (*Usine Nouvelle*, 1956, **12**, Aug.-Sept., 45, 47, 49, 51–53; Oct., 45, 47, 49, 51–53).

Apparatus, materials, abrasives, and types of tool and their treatment are dealt with in turn. The products of the Norton Co. are described in particular, the article being reprinted from one of their publications.

Researches on the Lapping of Metals. II. On Velocity and Lapping Fluid. H. Tsuwa. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1955, **5**, Oct., 411–417).

How to Choose the most Economical and Productive Speeds and Feeds for Metal Cutting. K. Skřivan. (*Czech. Heavy Ind.*, 1956, (2), 12–20). A discussion with graphical and mathematical treatments of various aspects of machining. Conclusions are drawn, particularly that the old rule as to the advantage of a thin chip has no general validity. The article is condensed from a book by the author.

Trepan Boring. With Special Reference to High-speed Deep-hole Trepan Boring using Tungsten Carbide Tipped Tools. A. H. Bennett. (*Iron Steel Inst., Spec. Rep.*, 60, 1957, 60–70).

Impact Grinder for Ultrasonic Machining. (*Australian Mach. Prod. Eng.*, 1956, **9**, Sept., 47–50). An account of the Raytheon impact grinder is given.

Principles and Applications of Spark Machining. D. W. Rudorff. (*Inst. Mech. Eng., Advance Copies*, 1957, pp. 13). A comprehensive review of technique, circuits, factors controlling efficiency, applications and results, with an account of surfaces produced and illustrations of samples of work is presented.

Metal Working by Electric Spark. M. M. Bruma. (*Rivista Mecc.*, 1955, **6**, Oct. 1, 43–47). [In Italian]. The method described uses as an electrode one of the metal parts to be worked and a high density current of the order of 100,000 amps per square millimetre, applied for very short times of the order of the micro-second. The scope and results of the method are described.—M. D. J. B.

Some Observations with the Electric Spark Machining Process. G. R. Wilms and J. B. Wade. (*Metallurgia*, 1956, **54**, Dec., 263–268). In a study of the spark machining of aluminium, antimony, chromium, and iron, evidence has been found that both deformation and cracking of the surface can occur. These can be removed by subsequent polishing. It is suggested that metal removal is effected by thermal rather than purely mechanical means.—B. G. B.

Influence of Heat Conductivity on Electrical Erosion of Metals. A. S. Zingerman. (*Zhur. Tekhn. Fiz.*, 1956, **26**, (9), 2008–2020). [In Russian]. The melting of the metal is carried out by heat which is transferred to the electrode from the discharge channel and distributed in the metal due to heat conductivity. The depth of the eroded metal is determined by: thermal properties of the metal, area of contact of the discharge channel with the electrode, and the energy evolved in the discharge channel. The diameter of erosion is determined by the cross-sectional area of the discharge channel. Processes taking place in the discharge channel have a material influence on the volume of eroded metal.—V. G.

Novelties and Trends in Methods of Production. Application of Electro-erosion to Metal Machining. H. Opitz. (*Usine Nouvelle*, 1956, **12**, July 26, 29). A brief review.

CLEANING AND PICKLING

The Degreasing of Metallic Surfaces. A. Bayon. (*Métaux–Corrosion–Indust.*, 1956, **31**, Dec., 513–517). A review of methods employed on an industrial scale for the degreasing of metal parts is presented.—B. G. B.

Metal Cleaning and Finishing by the Airless Abrasive Blasting Process. F. W. Pedrotty. (*J. Inst. Prod. Eng.*, 1957, **36**, Feb., 128–135). A review of uses of sand-blasting and of types and sizes of abrasives is followed by an account of the Wheelabrator projector, standard and special equipment, and special uses, such as steel strip descaling and mill roll etching.

Flame Cleaning of Gas Works Structures. A. R. Myhill. (*Gas Times*, 1957, **90**, Jan. 4, 28–29, 31). The practice and cost of flame cleaning of gas holders are reviewed.

Applications of Ultrasonics in Cleaning. J. Dory. (*Usine Nouvelle*, 1956, **12**, July 5, 90–91). Theory and a discussion of cavitation phenomena are given, and apparatus used is briefly reviewed.

Surface Preparation of Cast Iron. G. Bolognesi. (*Rivista Mecc.*, 1955, **6**, Dec. 10, 39–41). [In Italian]. A brief review is given of methods of preparing cast iron surfaces. Particular reference is made to the Kolene–Heurtey No. 4 method developed in the U.S.A. by the Kolene Corporation.—M. D. J. B.

The Use and Properties of Non-Flammable Liquids in Manufacturing Processes. D. Milne. (*Steel Processing*, 1956, **42**, Dec., 686–691, 714). Hydraulic fluids, cutting and cleaning liquids, rust-proofing agents, and quenching oils are discussed and the use of emulsions and other non-inflammable compositions in place of petroleum-base and similar fluids.

American Barrelling Techniques Available in Britain. (*Indust. Finishing*, 1956, **9**, Nov., 219–221). The Almco Supersheen process and the machines available are described.

Non-Mechanical Methods of Metal Brightening. I. Stainless Steel. H. Silman. (*Product Finishing*, 1956, **9**, July, 168–171). The general principles of electrolytic and chemical polishing methods are discussed. Electrolytic polishing methods for stainless steels are briefly described.—A. D. H.

Contribution to the Study of the Electro-polishing of Steels. J. Ibarz Aznarez and S. Feliu Matas. (*Rev. Cienca Apl.*, 1956, **10**, May-June, 233–240). [In Spanish]. Further work with the authors' sulphuric acid–ethyl alcohol–methyl alcohol bath is reported. The behaviour of a high carbon and austenitic stainless steel was investigated and it is concluded that: (*a*) a passive state must exist sufficient to prevent corrosion spots but there must still be an appreciable rate of anodic dissolution, (*b*) the polishing film must be partially soluble in the bath, and (*c*) at first a large number of pits develop in the polishing scratches and their spread and unification favourably affects the flatness of the surface. (10 references).—P. S.

Features of Anodic Behaviour of Steel in an Electropolishing Electrolyte for Low Density Polarizing Currents. G. S. Vozdvizhenskii, A. Sh. Valeev, and G. A. Gorbachuk. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **108**, (2), 299–301). [In Russian]. Carbon steel, treated by an electrolyte H_3PO_4 70%, C_rO_3 14%, H_2O 16% at a low density polarizing current, developed, just below the surface layer, dark spots which on analysis proved to be composed of iron with a small amount of phosphate. This is explained to be due to the passivation of the surface layer under the influence of chromates.—S. I. T.

Control of the Optimum Conditions for Electrolytic Polishing and Some Recent Progress in Research on New Baths. I. Épelboin. (*Métaux–Corrosion–Indust.*, 1956, **31**, Dec., 475–482). A detailed review of the factors influencing the electrolytic polishing process is presented. The determination of the optimum frequency of the alternating current and the optimum concentration of the polishing bath are described. Results obtained using polishing baths which do not contain perchloric acid, and hence are much less dangerous show much promise.—B. G. B.

An Electron Diffraction Study on the Mechanism of Electrolytic Polishing of Stainless Steels. G. Shimaoka and K. Niwa. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Sept., 441–445). [In Japanese]. The process was studied with 18–8 and 18-Cr steels in an electrolyte containing a 1 : 3 : 1 mixture of H_2SO_4, H_3PO_4, and glycerine, and chemical changes occurring at various stages are elucidated. It is concluded that, during brightening, dissolution and formation of surface oxide proceed almost continuously in the condition in which an amorphous oxide layer covers the surface, and this produces a bright surface.—K. E. J.

Equipment for the Production and Inspection of Highest Surface Finish, Part II (Inspection Apparatus). K. W. Michler. (*Metall*, 1956, **10**, Sept., 809–812). Instruments described comprise the 'Visoport' surface tester, 'Sigma' Microtest, and Perth-O-Meter. Working principles and illustrations of the instruments are given. The Perth-O-meter is described in greatest detail, which includes performance figures.—J. G. W.

Studies of the Pickling Process. W. Lueg, W. Dahl, and H.-J. Engell. (*Stahl u. Eisen*, 1956, **76**, Dec. 13, 1678–1685). Loss in weight and the e.m.f. connected with it were measured during pickling of hot rolled strip or heat treated specimens. For hot rolled strip, loss in weight commences after the acid has penetrated the pores and cracks in the scale resulting in change of potential against the standard hydrogen electrode, i.e. the dissolution rate of wustite increases with decreasing potential. Scale resulting from heat-treatment is almost free from pores and cracks and shows a layer-like structure consisting in the order metal–wustite–magnetite–haematite.—T. G.

Low Temperatures and Longer Immersion Times Reduce Pulling. (*Iron Steel Eng.*, 1956, **33**, Nov., 145, 147). Pickling of continuous welded pipe was studied and acid consumption reduced to 13·9 lb 60° Bé acid per ton.

A Study on Pickling Inhibitors. II. The Effect of Various Acid Pickling Inhibitors and their Electrochemical Properties. A. Adachi and S. Fujimoto. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Sept., 542–545). [In Japanese]. Various electrochemical, weight loss, and other tests are described, in which the effects of xylidine, laurylamine, and several commercial corrosion inhibitors are determined.—K. E. J.

Waterborne Wastes of the Mineral Industries. New England—New York Region. B. P. Martinez. (*U.S. Bur. Mines, Rep. Invest.*, 5289, 1956, Dec., pp. 41). Plating and pickling wastes, effluents from iron ore production and from iron and steel production and fabrication are discussed with notes on disposal in each case.

PROTECTIVE COATINGS

Metal Rectifiers for Electroplating. D. J. Fishlock. (*Elect. J.*, 1957, **158**, Jan. 4, 26–29; Jan. 11, 98–101).

Porous Chromium Plating. Its Uses in Marine Engines. A. Kaichinger. (*Shipbuilder and Marine Engine-Builder*, 1957, **64**, Jan., 38–40). The plating is intended to hold lubricant and is used in Diesel cylinder liners. After the plating is worn off the wear continues to be slow, this is attributed to included hydrogen introduced into the basis metal during plating.

Nickel Plating for Engineers. (*Mond Nickel Co. Monograph*, pp. 72). Plating of stainless steel and other alloys is described, their surface preparation, the baths and processes used, the mechanical properties of the deposits, practice, uses, plant, and tests, with tables of useful data and 27 references.

Conservation of Nickel in Electroplating. V. L. McEnally Jun. and F. G. Brune. (*Metal Progress*, 1956, **70**, Dec., 89–92). Methods of procuring more uniform deposits with saving of up to one-third of the nickel used are discussed.

Electrochemical Test of the Tin Deposit and Passivating Layers of Tinplate. W. Katz. (*Stahl u. Eisen*, 1956, **76**, Dec. 13, 1672–1678). Tin deposits obtained by the hot-dip process are very much thicker than those by electrodeposition (2·3–4 μ and 0·4–1·5 μ, respectively). During hot-dipping an intermetallic phase, $FeSn_2$, is formed, whereas in electrotinning this compound is only obtained by a subsequent heat treatment. The author describes various methods, chemical and electrochemical, for the dissolution of the tin deposit and the intermetallic phase. The structure of the intermetallic compound was examined microscopically, its structure depends on the time of heat treatment. The passivation layers, i.e. the naturally or artificially produced transparent tin oxide films, were also studied, they were cathodically removed and their thickness determined from time/potential curves.—T. G.

Rapid Determination of the Weight of Tin Coating on Tinplate. T. Ando and H. Kato. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Dec., 652–655). [In Japanese]. Optimum conditions are established for the electrolytic iodimetric method. Values are equivalent to those obtained by normal iodimetry, and 0·05 lb/basis box lower than those by the alkaline electrolytic method.—K. E. J.

New Aluminized Coating. K. Rose. (*Mat. Methods*, 1956, **43**, March, 105). A spraying process used by Pontiac Motor Div. of General Motors is outlined with steel composition and valve performance.

Tests on the Hot Aluminising of Steel. J. Ferrer Flotats. (*Inst. Investig. Tec. Trabajos Presentados por la Seccion de Metalurgia y Metalografia, 28th Congress of Industr. Chemistry, Barcelona*, 1956). After reviewing difficulties associated with the application of an aluminium coating by diffusion, F. describes hot aluminizing tests carried out in Spain. The specimens were descaled and protected by various coatings, including copper sulphate, glycerine, an 80/20 solution of calcium chloride and sodium chloride, wax and ethyl alcohol, prior to immersion in a bath of 99·5% pure aluminium with the addition of 6 and 12% Si. The influences of time (1 to 40 minutes) and temperature (650 to 900° C) were determined.

It was found that Si reduced the thickness and hardness of the coating but made it more adhesive in the bend test. The thickness of the diffused layer is a function of time and temperature and of the alloying elements. It is essential to degrease and descale the steel and to use protectors.—R. S.

Manufacture of Bimetallic Articles in Iron–Aluminium. (*Tecn. Indust.*, 1956, **34**, Sept., 1303–1304). [In Spanish]. Three typical applications are briefly described. These are grey cast-iron/aluminium pistons, alloy steel/aluminium bearing bushes, and air-cooled diesel engine cylinders of steel/aluminium. An account of the technique of manufacture of the cylinders are given; the steel shell is dipped into molten, pure aluminium then transferred to a refractory mould so that an aluminium alloy can be poured round it.

Developments in Sprayed Metal Coatings. H. S. Ingham. (*Product Eng.*, 1956, **27**, June, 194–197). Spray metallizing is reviewed giving tables of coatings, their properties, costs, and consumption of acetylene, oxygen, and metal, suitable alloys and ceramics are also considered.

Zinc Coatings by Gun-Spraying. E. Sanchiz Jun. (*Dyna.* 1957, **32**, Feb., 41–43). [In Spanish]. The fundamentals of the process are indicated and the characteristics of the zinc coatings are described. This is followed by a brief discussion of methods of testing the coatings and of suitable fields of application.—P. S.

Stainless Steel Spraying. G. G. Caccia. (*Rivista Mecc.*, 1956, **7**, March 3, 25–29). [In Italian]. The author discusses the principle of metal spraying and shows how a stainless steel surface of the order of 1 mm thick can be deposited on to a base metal part. A variety of stainless steels suitable for spraying is listed. The examples described include the lining of pressure vessels and the surfacing of axles and rolls.—M. D. J. B.

Investigation of Metal Sprayed Composition Bearings. E. Kretzschmar. (*Technik*, 1956, **11**, June, 435–442). War-time investigations of metal-sprayed bearings are summarized. Details of recent work are described, in which powdered graphite is added to the metal spray. The metals comprised electrolytic copper, brass, tin bronze, and aluminium and zinc bearing alloys. Results of performance tests with pressure lubrication and with drip feed are quoted extensively. Deposits of bronze, Al–Si alloys, and bronze containing 8% graphite, on steel or cast iron shells were found suitable for sliding speeds of 60–1000 ft/min and bearing loads of up to 3550 lb/in².—J. G. W.

Quality Tests for Black Oxide Coatings on Steel. J. Doss. (PB.111725, 1955; *TIDU List* 563, pp. 13). An oxalic acid etching test is described and compared with salt-spray methods.

Developments in Protective Processes: The Phoscadising Process. (*Product Finishing*, 1957, **10**, Jan., 64–67). A three-coat process of phosphate, alloy, and sealing compositions is illustrated, with special resistance to salt spray and brine.

Plastics and the Corrosion of Iron and Steel. G. A. Curson. (*Corrosion Techn.*, 1957, **4**, March, 79–82). A review of plastic coating materials and processes for iron and steel. Epoxy resins, polythene, thiokol, shellac, "Araldite" and "Epikote" are surveyed.

Plastics-based Strippable Coatings. E. S. Lower and S. Cressey. (*Corrosion Techn.*, 1957, **4**, March, 83–85). Materials and processes are reviewed, hot-dip and cold-dip, using ethyl cellulose, polyvinyl alcohol, butyral, and chloride, latex, and proprietary substances.

Vinyl Plated Steel. (*Steel*, 1956, **139**, Sept. 3, 103). Experimental production of vinyl coated cold rolled steel sheets by U.S. Steel Corp. is noted.—D. L. C. P.

Rubber and Synthetic Resin Coatings as Protection against Corrosion in the Construction of Chemical Plant. H. Anders. (*Kunststoffe-Plastics*, 1956, **3**, (3), 281–284, 287–288).

Synthetics in Anti-Corrosion Coatings. F. Ohl. (*Kunststoffe-Plastics*, 1956, **3**, (3), 289–290, 293–296, 299). An account of all the common film-forming plastics and modified natural products.

Shotblasting of Cast Iron for Vitreous Enamelling. T. O. G. Wilkes. (*Found. Trade J.*, 1956, **101**, Dec. 20, 739–741). The manufacture and use of metallic abrasives for shot-blasting cast iron prior to vitreous enamelling is described with particular reference to the types of shotblasting machines now available.—B. C. W.

A Comparative Study of the Different Coefficients of Expansion of Cast Irons Intended for the Production of Enamelled Articles. P. Détrez. (*Fonderie*, 1956, Sept., 355–357). Comparative data are given for the mean expansion coefficients of a number of cast irons over various temperature ranges up to 600° C. It is concluded that the expansion coefficient of a cast iron is not significantly affected by variations in silicon up to about 3%.—B. C. W.

Thermal Expansion of Commercial Dry Process Enamels and Cast Irons. R. R. Danielson and D. V. Van Gordon. (*Amer.*

Ceram. Soc. Bull., 1956, **35**, Sept., 347–350). Using enamels and irons from seven plants on a quartz-rod dilatometer, expansion coefficients were determined. The effect of firing treatment was studied on five irons varying in combined carbon. Crazing and chipping are related to relative expansion and limitations of calculated values discussed. The expansion of the iron is markedly increased by firing and is related to carbon content. Difference in measured expansions of 67×10^{-7} is satisfactory, at 58×10^{-7} crazing occurs and at 83×10^{-7} chipping.

Leaded Porcelain Enamelled Steel Panels. (*Lead*, 1957, **20**, (6), 3). Panels for architectural use fired as low as 1000–1100° F are described.

Reclaiming Dry Process Enamel "Sweepings." W. T. Dyre. (*Amer. Ceram. Soc. Bull.*, 1956, **35**, Nov., 436–437).

Enamelled Sheets and their Uses. (*Usine Nouvelle*, 1956, **12**, Sept. 13, 29–31, 33). A review from U.S. sources.

Can One Dispense with Lead-Pigmented Paints for Paint Protection? H. Hebberling. (*Werkstoffe Korrosion*, 1956, **7**, Aug.-Sept., 433–435). The author discusses this question and decides that the answer is "No."—J. C. H.

Review of Recent Work Carried Out by the A.B.E.M. (Belgian Association for the Study, Testing and Use of Materials). J. Depireux. (*Acier Stahl Steel*, 1956, **21**, May, 223–227). [In French]. Recent developments in paints, synthetic resins, wash-primers, and inhibitors are discussed. Results of field tests are given.—M. D. J. B.

POWDER METALLURGY

Mechanism of Sintering of Metallic Substances. R. Palme. (*Metall*, 1957, **11**, Jan., 8–9). A simple account of the mechanism of sintering of single-phase metal powders is given, with particular emphasis on the sintering temperature and shrinkage.—J. G. W.

Influence of Self Diffusion Phenomena in the Powder Metallurgy of Pure Iron of Carbonyl Origin When Above and Below the A_3 Transformation Point. G. Cizeron and P. Lacombe. (*Rev. Mét.*, 1955, **52**, Oct., 771–784). By dilatometric measurements in isothermal conditions the sintering rate of very pure carbonyl iron powder has been determined at various temperatures between 630 and 900° C in dry, pure hydrogen. The respective roles of volume and grain boundary diffusions in the sintering process could be revealed and their activation energies measured. The importance of grain boundary diffusion in the complete elimination of pores has been confirmed by micrographic study. The part played by volume diffusion is confirmed since sintering stops as soon as the temperature slightly exceeds the $\alpha \rightarrow \gamma$ transformation point.—B. G. B.

Influence of Heating Below and Above the $\alpha \rightarrow \gamma$ Transformation Point on the Self-Diffusion Process in Sintering. G. Cizeron and P. Lacombe. (*Rev. Mét.*, 1956, **53**, Nov., 819–830). The influence of grain boundaries on the elimination of pores during sintering of carbon iron powder is shown by comparison of results carried out in the α- and γ-ranges. The influence of a preliminary heating above the A_3 point reduces considerably the rate of subsequent sintering in the α-range owing to the large increase in grain size. The increased grain size insulates the greater part of the pores within the crystals thus making their elimination more difficult.—B. G. B.

The Effect of Repeated [Thermal] Cycles through the A_3 Transformation Point on the Structure of Small Bars of Sintered and Compacted Iron. G. Cizeron and P. Lacombe. (*Compt. Rend.*, 1956, **243**, Oct. 1, 951–953). Fritted carbonyl iron powder is distorted into conical forms by repeated passage through the A_3 point. These appear at random in cylindrical specimens but are ordered in those of rectangular section. Dislocations are formed and a polygonized structure results.

On the Sintered Iron Compacts. I. Effects of Particle Size on the Properties of Sintered Iron Compacts. II. Effects of Powders of Various Origins on the Properties of Sintered Iron Compacts. T. Watanabe. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Oct., 516–520; 520–525). [In Japanese]. I. Particle sizes and mixtures of sizes in the range 50–300 mesh were investigated in crushed electrolytic powders. The effects of size are most marked in compacts sintered at 1250–1300° C, and are classified into three main groups: 50–100 mesh, 200 mesh, and 300 mesh according to properties achieved. Differences in properties correspond closely with shrinkage and porosity in early sintering stages. With mixtures of particle sizes, the properties resemble those given by the predominant fraction. II. Carbonyl iron, reduced iron, reduced mill scale, electrolytic iron, crushed electrolytic iron, and crushed low-carbon steel were screened at 300 mesh, annealed, pressed, and sintered in hydrogen. The effects of origin are most marked in compacts sintered at 1200° C. The differences in properties correspond with shrinkage changes. The powders can be classified into three main groups: carbonyl, reduced, and electrolytic or crushed powders.—K. E. J.

The Manufacture of Articles by Sintering. (*Tecn. Indust.*, 1956, **34**, June, 787–791). [In Spanish]. The importance of the sintering process as a method of manufacture is emphasized. The production, preparation, and sintering of iron powders by the DPG process (Deutschepulvergesellschaft) is outlined.—P. S.

Producing Powdered Metal Components. K. Roney. (*Elect. Times*, 1957, **131**, Jan. 10, 41–44). Parts of electrical apparatus are dealt with.

Porous Bodies. (*Usine Nouvelle*, 1956, **12**, Aug. 9, 29–30). The production from powdered metals of self-lubricating compacts is described and their properties outlined.

Rate of Capillary Rise of Liquid Metal in a Higher Melting Metal Powder Compact. K. A. Semlak, C. W. Spencer, and F. N. Rhines. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Jan., Section 2, 63–64). To obtain a better understanding of sintering in the presence of a liquid phase, the rate of capillary rise has been measured in the case of liquid copper, saturated with iron, and a partially sintered iron compact in a hydrogen atmosphere. The rate follows a parabolic law.—G. F.

FERRITES, CERMETS, AND CARBIDES

On the Structure of Calcium Ferrite, Chromite and Vanadite, R_2CaO_4: (R = Fe, Cr, V). E. F. Bertaut, P. Blum, and G. Magnano. (*Acta Crystallographica*, 1957, **10**, Mar. 10, 238). [In French].

Interpretation of the Magnetic Properties of the Ferrites $5Fe_2O_3$, $3M_2O_3$, Where M = Y, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu. R. Pauthenet. (*Compt. Rend.*, 1956, **243**, Nov. 26, 1737–1740).

Crystallographic and Magnetic Investigation in the System Lead Oxide–Iron Oxide. (PbO–Fe_2O_3). W. Berger and F. Pawlek. (*Arch. Eisenhüttenwesen*, 1957, **28**, Feb., 101–108).

Studies on Oxide Magnets. Effects of Bi_2O_3 on the Magnetic Properties of Ba, Sr and Pb Ferrites. T. Okamura, H. Kojima, and S. Watanabe. (*Nippon Kinzoku Gakkai-Si*, 1955, **19**, Aug., 464–468).

Crystallographic Studies on Perovskite-Like Compounds. III. $La(Mx, Mn_{1-x})O_3$ with M = Co, Fe and Cr. M. A. Gilleo. (*Acta Crystallographica*, 1957, **10**, Mar. 10, 161–166). The materials may be ferromagnetic, but not at liquid N_2 temp. if M = Fe.

Solubility of Boron in Fe_3C and Variation of Saturation Magnetization, Curie Temperature, and Lattice Parameter of $Fe_3(C, B)$ With Composition. M. E. Nicholson. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Jan., Section 2, 1–6). By means of metallographic and X-ray studies and Curie temperature measurements, the author shows that, at 1000° C, 80% of the carbon in Fe_3C can be replaced by boron. It is suggested that an electron transfer occurs between the interstitial elements and the 3d shell of iron, and that the solid solubility depends both on a similarity of atomic size of the interstitial elements and on the influence of the solute atoms on the electron density of the 3d shell of iron.—G. F.

Borides as Tool Materials. American Electro Metal Corporation. (PB 111749, 1954, Oct., pp. 90; *TIDU List* 674).

New High-Temperature Intermetallic Materials. W. Arbiter. (PB 111413; *TIDU List* 684, 1953, pp. 90). Oxidation behaviour at 1000° C/24 h and transverse rupture strength showed 95/5 Cr_2Ti/Cr_2O_3 to be the best of a series of binary Ti, Cr, Zr, Fe, Ni, Co, and Si compositions. Cr_3Si and 95/5 Cr–Zn had good oxidation resistance but low high-temperature strength. Production and testing are described.

Infiltration of Cermets for Improved Toughness. C. G. Goetzel and J. B. Adamec. (*Metal Progress*, 1956, **70**, Dec., 101–106). Composite structures produced by impregnating porous titanium carbide compacts with a metallic binder

have superior impact strength and oxidation resistance to those of conventional cermets.—B. G. B.

Refractory Materials for Use in High-Temperature Areas of Aircraft. N. R. Thielke. (PB 121046; *TIDU List* 684, 1955, pp. 94). Cermets based on sintered carbides are studied for possible correlation between fracture pattern and microstructure and for oxidation behaviour, especially the TaC–NbC–TiC system. Other studies on aluminium titanate and a section on thermal shock tests are included.

Investigation of the Effect of Raw Material Production Variables on the Physical and Chemical Properties of Carbides, Nitrides and Borides. H. Blumenthal. (PB.111989; *TIDU List* 674, 1955, pp. 104). Only titanium carbide is here dealt with.

PROPERTIES AND TESTS

Destructive and Non-Destructive Testing. F. T. Galton. (*Australasian Eng.*, 1956, **48**, Sept. 7, 68–71). Standard tests are briefly indicated and their applications to forgings and pressings, castings and welded fabrications outlined. Special attention is given to welds.

Non-Destructive Methods of Testing. l'Association des Industriels de Belgique. (*Compt. Rend. Gén. des Trav. de la Conf. Internat. sur les Méthodes Non-Destructives pour l'Etude et le Contrôle des Materiaux, May*, 1955, Dec. 1956, pp. 393). **National Reports.** (82–252). This section consists of reports from 17 countries on the position of non-destructive testing, research and similar institutes, and apparatus commercially available in each. All sorts of materials are included and few actual data are given. **Radiology.** (X-Rays, β- and γ-rays). (Germany), H. Möller (82–85); (Austria), E. Uhlir and K. Schreier (104–105); F. Regler, E. Krainer, and J. Zavodsky (108–109); (Belgium), J. Strebelle (112–115); (Canada), M. L. Baxter, M. E. P. Faquier, W. E. Havercroft, M. G. E. Neapole, and P. J. Stewart (124–126); (Denmark), H. Vinter (131–132); (U.S.), Society for Non-Destructive Testing; E. E. Charlton, J. W. Dutli, N. A. Kahn, R. G. Tobey, N. C. Miller, D. T. O'Connor, W. H. Canter Jun., and J. H. Bly (147–164). The U.S. sections are better than the others and give lists of facilities, apparatus, and ancillary materials available. (France), G. Pomey and H. Mallet (187–190); (Britain), W. E. Schall (204–206); (Norway), G. Fagerholt (227); (Holland), D. Binkhorst, W. J. Kaufman, J. Oostling, and B. Schuil (231–232); (Sweden), H. Swedenborg (243); (Switzerland), (247). **Ultrasonics.** (Germany), E. Martin (86–88); (Austria), E. Skudrzyk, H. Kraimer, K. Schreier, and Kottas (106); (Belgium), G.-A. Homès (115–118); (Canada), (126–127); (Denmark), S. A. Lund, (132–133); (U.S.), W. C. Hitt, P. K. Bloch, J. C. Smack, and D. C. Erdman (165–172); (France), P. Bastien (190–198); (Britain), D. G. W. Claydon (206–212); (Norway), G. Fagerholt (228); (Holland), W. de Jong, B. v. d. Glas and A. de Sterke (232); (Sweden), (243–244); (Switzerland), (247–248). **Magnetic, Electrical and Related Methods.** (Germany), F. Förster (88–93); (Austria), H. Krainer (107, 109); (Belgium), J. Strebelle (119–120); (Canada), (127–129); (Denmark), S. A. Lund (133–134); (U.S.), F. B. Doane, T. de Forest, H. N. Staats, and J. F. Torbert (173–178); (France), L. Colombier (198–203); (Britain), R. H. Wallace (212–216); (Norway), (228); (Holland), P. G. Boting, M. J. Bottema, and A. van Spijk (233); (Sweden), (244); (Switzerland) (248). **Other Methods of Non-Destructive Testing.** (Germany), O. Vaupel (93–94, 98–103); R. Berthold (94–98); (Austria), J. Zakowsky (110), (110–111); (Belgium), G.-A. Homès (120–121, 121–123); (Canada), (129–130); (Denmark), S. A. Lund (134); H. Vinter (134–137); (U.S.), A. Doschek and W. A. Cannon Jun. (178–183); (Britain), R. H. Herz (216–219); (Norway), A. Petersen, A. Naess (229–230); (Holland), B. v. d. Glas and B. Schuil (233–234); A. H. O. W. de Bats, J. Steenhuizen, A. J. Zuithoff, and L. van Ouwerkerk (234–236); (Sweden), (244–246); (Switzerland), (249–250). **General Topics concerning the activities of the profession of Non-Destructive Control in the U.S.** G. H. Tenney (183–184). **Non-Destructive Testing in Spain.** D. M. de Miro-Ramonacho (138–144). **In Finland.** J. E. Holmström (185–186). **In Italy.** G. Moravia (220–226). **In the Sarre.** H. J. Seemann (237–242). **In Jugo-Slavia.** M. Radojkovic (251–252). **Reports of a National Character.** (253–286). These deal in greater detail with a few more specialized topics. **Japan.** H. Kihara (254–256); K. Fujimoto and H. Sano (257–261). Direct X-ray magnification by $\times$ 2 or $\times$ 3 is described. J. Yamanouchi, N. Takagi, and N. Niwa (262). A standard sensitivity block for ultrasonic flaw detection is described. K. Tezuka and K. Yamakawa (263–266). Control of welds with magnetic powders. Y. Ishii and M. Nakata (266–270). X-Ray measurement of residual stresses is described using a Geiger Counter. **Contribution of the New Zealand Institute of Welding.** E. J. Barnard (271). **The Development of the Ultrasonic Defectoscope in Poland.** I. Malecki (272–274). **Use of Radioisotopes for Research on Flaws in Welds and Castings in the U.S.S.R.** S. Nazarov (275–281). **The Problem of the Practical Application of Ultrasonics to the Study of Homogeneity in Metals and Ceramics.** S. Sokolov (282–285). **Non-Destructive Methods in the Union of South Africa.** C. W. du Toit (286). **General Reports and Discussions.** (287–393). The papers above are summarized, extended, and various topics are discussed.

Non-destructive Testing and the Production Engineer. W. G. Cook. (*J. Inst. Prod. Eng.*, 1957, **36**, Feb., 97–109, 96). A review of techniques with notes on standards, attitudes to inspection, and problems of large numbers and a special section on the detection of rare defects in critical components.

The Scope for Physical Chemistry in Metallurgy. G. Heynert. (*Stahl u. Eisen*, 1956, **76**, Aug. 9, 1049–1052). A review based upon four IRSID publications: Givandon (*Cahiers du Cessid*, 1952, No. 1); Vallet (*ibid.*, 1954, No. 8); Rey, and Kozakevitch and Urbain (*ibid.*, 1954, No. 9).

Experiments and Numerical Determination of the Cutting Properties of Knives with Special Reference to Stainless Steel. W. Müchler. (*Forsch. Wirts Nordrhein-Westfalen*, 1956, No. 277, pp. 47). Structures, heat treatments, and hardness are related to cutting quality and wear of blades, mostly of 0·42% C and 13·75% Cr steel.

A Study of Temper-Brittleness in Cr–Mn Steel containing Large Amounts of Molybdenum, Tungsten, and Vanadium. A. E. Powers. (*J. Iron Steel Inst.*, 1957, **186**, July, 323–328). [This issue].

Effect of Minor Elements on Drawability of Mild Steel Plates. R. Nakagawa et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 880–881). [In Japanese]. The influence of tin (0–0·045%) in lowering the Erichsen value and on the tensile properties is described. The effects of Cr, As, Cu, and Ni in lowering the Erichsen value are illustrated graphically.—K. E. J.

Influence of Impurities on the Quality of Low Carbon Killed Steel for Tube Rounds. M. Kato et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 878–879). [In Japanese]. The relationships between the number of internal cracks and the quantity of Mn, S, Mn/S ratio, number of internal sand marks, and number of black spots are investigated.—K. E. J.

The Effect of Chromium on High-Manganese Cast Steel. R. Niwa et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 871–873). [In Japanese]. The increase in hardness and yield point and decrease in tensile strength and elongation as chromium content is increased to 11% are followed. For steels containing 0–4% Cr the relationships between amount of hammering and reduction ratio and hardness are shown: increase of chromium content markedly reduces the reduction ratio. Changes occurring as 2% Cr–Mn steels are held for varying periods after solution treatment at 1050° and 1100° C are discussed.—K. E. J.

Influence of Mn on the Properties of Cr–Mo Case-Hardening Steel. K. Kiyonaga et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 874–875). [In Japanese]. As the manganese content is increased from 0·5 to 2·25%, the distortion ratio increases, particularly with amounts above 1·75%. Increase of manganese content in the same range increases the quenched hardness of the carburized case in some examples.—K. E. J.

Evolution of the Use of Molybdenum in French High-grade Iron and Steel Making. L. Colombier. (*IVe Salon de la Chimie.—Journée des Aciers Speciaux, Versailles*, Nov., 1956, pp. 14). Stainless and heat-resisting types are reviewed.

Effects of Niobium and Nitrogen on the LCN 155 Heat-Resisting Steel. On the Precipitation in Tempering after Solution Treatment. T. Masumoto. (*Tetsu to Hagane*, 1956, **42**, Sept., 779–781). [In Japanese]. The effects of solution treatment temperature and contents of Nb and N on the thermal expansion curves between 0° and 1100° C are discussed for six specimens (compositions given).—K. E. J.

How Much Does Lead Change Steel? (*Steel*, 1956, **139**, Oct. 29, 122–123). The results of an investigation are reported, in which 2 types of steel were tested in the non-leaded and leaded conditions. Comparison of results led to the following conclusions on the effect of lead addition: Brinell hardness, yield, and tensile strengths not affected; grain size a little

smaller; Charpy impact transition temperatures average 22° F lower.—D. L. C. P.

Some High Temperature Alloys. W. Norden and G. R. Barrow. (*Métaux–Corrosion–Indust.*, 1956, **31**, Dec., 488–499). An examination is made of rolled and forged alloys used in gas turbines. Their composition and high temperature properties are described in connection with the conditions of service. Special mention is made of a new American alloy Hastelloy R 235 made by vacuum fusion and used for super duty blades. The majority of alloys considered have been developed by the Union Carbide and Carbon Corporation, U.S.A.—B. G. B.

Study on 6–5–4–2 Type High Speed Steels. T. Onishi et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 777–779). [In Japanese]. Comparative tests were made on (i) 6–5–4–2 steels, (ii) 18–4–1 steel, and (iii) the latter with addition of 5·3% of cobalt. The relationships between drawing temperature and hardness for various quenching temperatures are shown. Cutting tests showed the best results with type (i) for drills, but with type (iii) for lathe tools; the optimum quenching and drawing temperatures for each type are given.—K. E. J.

Fe–Al–Mo Alloys for High-Temperature Use. J. F. Nachman and W. J. Buehler. (*Metal Progress*, 1956, **70**, Dec., 107–110). The light weight, excellent oxidation resistance, and high strength at elevated temperatures of Thermenol alloys (Fe–Al–Mo) indicate their potential utility as replacements for iron–chromium and iron–chromium–nickel alloys. Thermenol alloys contain 10 to 18% Al and 2 to 4% Mo.—B. G. B.

Study on Leaded Free-cutting Steel. I. Mechanical Properties and their Direction Effect. Y. Yasuda et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 833–835). [In Japanese]. Mechanical properties, hardnesses, and impact values are given for tempering temperatures between 300° and 700° C. The variation of hardness between the centre and the surface of cold-drawn bars is depicted for plain-carbon and leaded steels; hardnesses for the latter are approximately 60% of those for the former. The variations of bending and torsional fatigue values with the diagonal or perpendicular direction are shown for carbon steel (S 50 C), leaded steel (H 50 L), and resulphurized steel (SAE 1196).—K. E. J.

On the Effect of Carbon Content in High Speed Steel. K. Katagiri and K. Machi. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, July, 401–405). [In Japanese]. Type 16–4–1 steel with carbon in the range 0·63–0·92% was studied. The quenched hardness falls as the carbon content, and also the quenching temperature (1260–1290° C) rise; with these increases, however, the tempering temperature at which the steel gains its highest secondary hardness rises. The steel partially melts above 1270° C when the carbon content is 0·90%. All specimens quenched at the same temperature gain nearly the same hardness when tempered at specific temperatures.

Studies on Nickel-Base Heat-Resisting Alloys. I. O. Ochiai et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 775–776). [In Japanese]. Tests were made on 19–9 DL, Timken 16–25–6, N 155, S 816, Nimonic 80 and 90, Inconel X, and M 252. Results are given for the age-hardening characteristics (up to 1000 h) at 750° C, the effect of air-cooling or water quenching on hardness after solution treatment at 1065° C, and the effects of Co, Mo, and Nb on the age-hardening characteristics at 750° and 850° C.—K. E. J.

Study on Chromium-base Heat-resistant Alloys. I. K. Suenaga. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Oct., 491–496). [In Japanese]. Preliminary investigations into Cr–Mo–Fe alloys of composition 60 : 15 : 25, for casting, are reported. The alloys are hard to prepare, having high m.p., and the difficulty increases as iron content is reduced. They are hard, with good high-temperature creep strength and low thermal expansion, but are brittle at room temp. As carbon content is increased up to 0·4%, the alloys are easier to prepare and hardnesses and creep strengths increase but ductility decreases.

Study on the Hot-Workability of Steels. V. Hot-working Properties of Austenitic Stainless Steels. T. Morishima. (*Tetsu to Hagane*, 1956, **42**, Sept., 928–930). [In Japanese]. The effects of oxygen content on the hot-workability of 18–10 and 18–12 Mo stainless steels at 1100, 1200, and 1300° C, and of S, Al, Ti, Cu, P, N_2, C, Ni, Mn, Si, Cb, and Mo on the hot-workability of 18–10 steel at 1200° C are discussed.

Tips on Aircraft, Missile Metals Control. C. W. Mell. (*Western Metals*, 1956, **14**, Nov., 83–84). Failures in performance tests due to cracks or inclusions and incorrect heat treatments are shown. Precautions to be taken in purchase, storage, and identification are briefly indicated.

Central Laboratories of Iron and Steel Enterprises. (*Zavodskaya Laboratoriya*, 1956, **22**, (2), 248–252). [In Russian]. The organization, staff, and work of central laboratories at the Kuznetsk and Magnitogorsk metallurgical combines and at the Novo Tagil' metallurgical works is discussed. Some shortcomings in the work of central works laboratories of tube-rolling works are outlined.—S. K.

METALLOGRAPHY

On the Ordered Arrangement of Interstitial Atoms in Interstitial Solid Solution. I. The Equilibrium between Supersaturated Ferrite and Martensite in Iron–Carbon Alloys. H. Sato. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Dec., 601–605). [In Japanese]. The case of α-iron containing interstitial carbon is treated as a superlattice, theoretically, since experimental methods cannot easily detect small solubility figures and X-ray scattering. It is concluded that martensite is more stable than supersaturated ferrite at low temperatures; that the transition point between the two rises linearly with temperature, reaching room temp. at 0·2% C; and that preferential distribution of carbon atoms appears spontaneously.—K. E. J.

On the Ordered Arrangement of Interstitial Atoms in Interstitial Solid Solution. II. The Configuration of Interstitial Solute Atoms in Face-Centred Cubic Lattice. H. Sato. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Dec., 605–607). [In Japanese]. The general characteristics are analogous to the superlattice in binary substitutional alloys with face-centred cubic lattices. The interaction energy shows that carbon atoms in austenite would be randomly distributed. In the Fe–N system, Fe_4N has been observed; despite the face-centred lattice, it is ferromagnetic.—K. E. J.

Construction of a Vacuum Electric Furnace with a Graphite Heater. V. S. Kutsev, B. F. Ormont, and V. A. Epel'baum. (*Zavodskaya Laboratoriya*, 1956, **22**, (2), 244–245). [In Russian]. A graphite-element furnace for the study of high-temperature equilibria involving metal oxide reduction and carbide formation is briefly described. The design incorporates several advantageous features and enables temperatures of 2000° C to be obtained when working at 5–6 kW.—S. K.

The Application of Colour Micrography to the Study of Cast Irons. (*Fonderie*, 1956, Sept., 339–340). Six colour micrographs obtained by etching cast irons (white, malleable, and spheroidal) in boiling sodium picrate solution, are presented and discussed. In addition to the normal metallographic structure the reagent reveals segregation in the matrix.

Some Studies on Isothermal Transformation and the Behaviour of Retained Austenite for High Speed Steels. S. Koshiba, K. Tanaka, and A. Inada. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Sept., 517–521, 521–524). [In Japanese]. I. When the specimen was held at 250–300° C in the bath, the Ar″ transformation occurred with difficulty on cooling because lower bainite had formed, and stabilized the austenite. More martensite was retained at room temperature, and the secondary Ar″ transformation on tempering was increased more than by oil quenching. With a long holding time at 600° C, there were two stages of expansion on cooling; the retained austenite was decreased at room temperature, and the secondary transformation on tempering was reduced. II. Changes in the tempering curve, intensity of magnetization and the relationship between tempering temperature and hardness were explored in steels subzero-treated at − 75° C and isothermally heat-treated at 100°, 300°, and 600° C. Subzero treatment transformed retained austenite to martensite considerably, giving a hardness increase of Rc 1·5–2·0, and increased intensity of magnetization; the treatment, however, had little effect on specimens treated for 20 hours at 300° C.—K. E. J.

On the Relation between Austenitic Grain Size and Aluminium Nitride. K. Kato et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 782–784). [In Japanese]. Sixteen steels (compositions given) had additions of aluminium of 0–0·150%. They were analysed for total Al, Al_2O_3, AlN, and austenitic grain size. A relationship with considerable scatter is shown between the AlN content and the grain size number. The effects of hot working on these parameters are discussed.—K. E. J.

A Study of the Kinetics of Martensitic Transformation and Stabilisation of Austenite. C. Crussard and J. Philibert. (*Rev.*

Mét., 1956, **53**, Dec., 973–980). Isothermal and anisothermal martensitic transformations proceed by a unique mechanism: thermally activated nucleation and athermal growth. Stabilization hampers nucleation and appears only when two factors are present: chemical (carbon, nitrogen) and physical (plastic strain, dislocations). The effect of carbon and nitrogen on the kinetics of martensitic transformation is discussed.—B. G. B.

The Bainite Transformation in Steels. L. Habraken. (*Rev. Mét.*, 1956, **53**, Dec., 930–944). A study is described on the bainitic transformation in eutectoid and hypoeutectoid steels and includes the study of upper and lower bainite and probainitic ferrite. The kinetics of the transformation appear as a result of a transformation of the martensitic type (without diffusion) and of a double mechanism of diffusion similar to that described by Krisement and Wever. Electron microscopy was extensively employed in the study and carbon steels and low alloyed Cr, Mo, V, W steels were used.—B. G. B.

Thermodynamic Activities in Iron–Cobalt Solid Solutions. T. Satow, S. Kachi, and K. Iwase. (*Sci. Rep. Res. Inst. Tôkohu Univ.*, 1956, **8A**, Dec., 502–510). Thermodynamic properties of α, γ, and superlattice phases were studied from equilibria with water and hydrogen. In the γ-phase region entropy of mixing is almost ideal; in the α-phase activity shows negative deviation from Raoult's law and heat of mixing was negative. The effect of superlattice formation is seen in the signs of the partial molal configurational entropies of 49·7 and 51·9 atom% Fe alloys which were opposite and numerically coincided with theoretical values.

Steels High in Chromium. W. Peter. (*IVe Salon de la Chimie.—Journée des Aciers Spéciaux, Versailles*, Nov., 1956, pp. 22). Chrome steels are classified on the basis of the α–γ transformation and high-chromium martensitic, ferritic, and semi-ferritic steels are discussed, their compositions and properties tabulated and various transformation and other curves appended.

Sigma-Phase in Certain Ternary Systems With Vanadium. J. B. Darby Jun. and P. A. Beck. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Jan., Section 2, 69–72). The six ternary systems V–Fe–Co, V–Fe–Ni, V–Co–Ni, V–Mn–Fe, V–Mn–Co, and V–Mn–Ni, have been investigated by microscopical and X-ray means, and isothermal sections prepared. In all cases the σ-phase forms a relatively narrow elongated field in the ternary system, connecting with the binary σ-phases.—G. F.

Liquid Immiscibility in Metal Systems. B. W. Mott. (*Phil. Mag.*, 1957, **2**, 8th Series, Feb., 259–283). A modified Hildebrand rule, into which an electronegativity term is introduced, accounts for 426 out of 529 alloy systems considered instead of 312 without the additional term. The exceptions and other topics are discussed.

Study on High-Chromium Steel. III. On the Anomaly of α-Solid Solution of Fe–Cr System at High Temperature. Y. Imai and K. Kumada. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, July, 406–408). [In Japanese]. Effects of annealing steels containing over 15% of chromium at 500° C on the shift of the magnetic transformation point are explained well by the formation of the superlattice Fe_3Cr alone.—K. E. J.

The Constitution of Alloys of Iron and Manganese with Transition Elements of the First Long Period. A. Hellawell and W. Hume-Rothery. (*Phil. Trans. Roy. Soc.*, 1957, **249**, Mar. 14, 417–459). An accurate determination of the iron- and manganese-rich binary systems with Ti, V, Cr, Co, Ni, and Cu is reported. Both thermal analysis and microscopical and X-ray methods were used with materials of highest purity. Techniques, the diagrams, and full thermal data and analyses are presented.

CORROSION

Forum on Corrosion Research, Sponsored by Office of Naval Research. (*PB*.115046, 1949; *TIDU List* 630, pp. 80). Texts of 16 papers are given, three on electrochemical fundamentals, three on passivity and inhibitor studies, four on corrosion mechanisms, and six on high-temperature studies.

The Corrosion of Iron. S. Yamaguchi and Y. Aoyama. (*Werkstoffe Korrosion*, 1956, **7**, Nov., 626–628). Rust samples formed in Japan were shown by the electron microscope and by electron-diffraction to contain two modifications of ferric oxide: a ferromagnetic oxide with a γ-structure, and a paramagnetic oxide with an α-structure. The first is formed when iron is exposed to moist air and the second when iron is corroded by strongly oxidizing solutions or organic media.

Corrosion in New Zealand. A Summary of 90 Years' Experience by the Dominion Laboratory. T. Marshall. (*New Zealand Eng.*, 1956, **11**, Nov., 368–371). Atmospheric and underwater corrosion tests on steel and non-ferrous alloys are briefly considered. Corrosion in soil, during shipment, and by geothermal steam are also discussed.

Anaerobic Corrosion. L. T. Minchin. (*Coke Gas*, 1956, **18**, Dec., 495–497, 504). Bacterial attack on buried gas mains and similar structures is reviewed.

Caustic Cracking. Its Occurrence in Steam Boilers. D. D. Jones. (*Corrosion Techn.*, 1957, **4**, Feb., 56–59). The process and theories of its origin are discussed and its prevention considered.

Researches on Corrosion and Inhibition. Reaction Velocity in the System Iron : Dilute Acetic Acid at 40° C. G. S. Gardner, H. L. Faigen, G. L. Gibson, and W. S. Hall. (*J. Franklin Inst.*, 1956, **262**, Nov., 369–384; Dec., 469–478). The reaction was carried out in absence of O_2 at 1000 ppm acetic acid with two commercial inhibitors and in presence or absence of an oil phase. Reaction velocity constants and fractional surface covered are calculated in the second part. A quantity S, the fractional surface covered by inhibitor, is shown to be useful as an index of efficiency.

Kinetics of the Cathodic Processes during Corrosion of Metals in Soil. N. D. Tomashov and Yu. N. Mikhailovskii. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **107**, (6), 853–856). [In Russian]. An experimental study of the character and velocity of transfer of oxygen in moist soils has shown that there are definite relations, expressed by curves and formulæ, between the coefficient of diffusion on the one hand, and the strength of current and the degree of moisture of soil. The greatest amount of corrosion of iron occurs in soils of medium moisture.—S. I. T.

Our Present-day Conception of the Electrochemical Mechanism of Corrosion. II. W. Schwarz. (*Metall*, 1956, **10**, Oct., 921–925). In this part the phenomena taking place in an electrode consisting of two different metals are analysed. The theory developed is then applied to the action of inhibitors, of substances reducing the concentration of metallic ions, to the behaviour of a homogeneous electrode with partial differences of concentration, and to the phenomenon of passivity.—J. G. W.

Corrosion Tests in the Presence of Radioactivity. K. Lintner, E. Nachtigall, and E. Schmid. (*Metall*, 1957, **11**, Jan., 31–35). The corrosion resistance of aluminium and of aluminium alloys and of iron was tested in shafts of uranium mines and in the laboratory with more intensive irradiation. Corrosion was more rapid and more highly localized. Further work is needed to resolve the question whether the formation of peroxides in a radioactive atmosphere or some direct influence of radiation energy is responsible.—J. G. W.

An Estimate of Corrosion Losses to Underground Cables and Pipe Lines in Japan. M. Tanaka. (*Corrosion*, 1956, **12**, Oct., 513–514). Over the last few years the direct corrosion losses of underground cables and pipe lines in Japan are estimated to have cost only 200,000 dollars per annum. Details of the method of estimation are given.—J. F. S.

Behaviour of Petroleum-Type Preservative Compounds Under Service Conditions. H. Linden. (*PB*.118045, 1955; *TIDU List* 563, pp. 61). Outdoor storage tests on polished steel panels and cylinders are reported and a high rate of failure observed. Data are given for the 37 compounds tested.

Cathodic Protection. L. B. Hogben, J. A. Spencer, and P. W. Heselgrave. (*Institution of Electrical Engineers, preprint*, 2336, 1957, Feb., pp. 9). A general account is presented dealing with both sacrificial anodes and impressed currents. Soil resistivity measurement and effects on other nearby buried structures are discussed.

Major Factors in the Cathodic Protection of Steel in Sea Water. L. J. Waldron, E. E. Nelson, and M. H. Peterson. (*PB*.111807, 1955; *TIDU List* 668, pp. 21). Work of the Naval Research Laboratory is surveyed and existing theories are reviewed. The commonly accepted criteria for protection are inadequate in waters polluted with organic wastes and in presence of anaerobic bacteria and certain types of fouling. Water resistivity effects are discussed. Mathematical solutions are given for simple cases.

Intrinsic Protection of Water Mains. M. Unz. (*Corrosion*, 1956, **12**, Oct., 526–532). On water supply lines to an irrigation system in Israel bare or bituminous-coated steel pipes were anodic to cement coated pipes. External corrosion protection is essential. Electrically non-conducting pipe gives

a complete solution of the corrosion problem. With steel pipes, external attack is reduced by cement coatings and by separation of heterogeneous line sections. Prestressed concrete requires special attention to avoid internal corrosion. A reaction between the rust and the concrete is postulated to explain an observed increase in protective value at anodic areas.—J. F. S.

Performance of Galvanic Anodes for Cathodic Protection. E. E. Nelson and L. J. Waldron. (*PB.*118243, 1955; *TIDU List* 668). An interim report on Mg, Al, and Zn anodes connected to a large steel sea wall. High and low voltage anodes and some of the factors involved are discussed.

Cathodic Protection applied to Pipelines. J. B. K. Ley. (*Commonwealth Eng.*, 1956, **44**, Sept. 1, 39–44). Water mains are dealt with. The mechanism of corrosion is discussed.

Magnesium Anodes for Pipeline Corrosion Control. J. S. Gerrard. (*Pipes and Pipelines*, 1956, **1**, Nov., 15–19, 28).

A High Potential Magnesium Anode. P. F. George, J. J. Newport, and J. L. Nichols. (*Corrosion*, 1956, **12**, Dec., 627 633). A new magnesium alloy containing manganese is claimed to be superior to the usual alloys for sacrificial anodes. It will deliver 20–30% more current to a polarized cathode. In saline soils there is also an advantage in current efficiency. Polarization characteristics and corrosion distribution patterns are similar to those of the conventional magnesium—6% aluminium—3% zinc alloy anodes. Evidence from field trials and laboratory tests is given and a suggested mechanism for the improvement is proposed. The composition of the new alloy is not disclosed.—J. F. S.

Cathodic Protection for Oil Tankers. (*Shipbuilder and Marine Engine-Builder*, 1957, **64**, Jan., 12–13). The Guardion installations of F. A. Hughes and Co. in tankers are described. A three-stage magnesium alloy anode system with plate-type and variable booster anodes is used.

On the Cathodic Protection of Metals. III. On the Cathodic Protection of 13Cr Stainless Steel. I. Goro. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, July, 390–392). [In Japanese]. The steel can be protected by cathodic current in dilute HCl and H_2SO_4, but in dilute HNO_3 solution cathodic corrosion occurs as in 18–8 steel. Cathodic corrosion in 13Cr and 18–8 steels is caused by reduction of the protective oxide film; when this film gives good protection, cathodic current is of no value.

Effect of V and W on the Sulphurization-Resistant Property of Cast Iron at High Temperature. H. Nakai et al. (*Tetsu to Hagane*, 1956, **42**, Sept., 811–813). [In Japanese]. Specimens were exposed to H_2S under stated conditions. The change in weight fell linearly as the tungsten content was increased from 0 to 10%. A more rapid fall was found as the vanadium content was increased from 0 to 8%. Spectrographic investigations of three layers of different depth in the specimens are reported.—K. E. J.

Corrosion and Corrosion Resistant Coatings. J. H. Payne. (*Inspection Eng.*, 1957, **21**, Jan.-Feb., 2–10). A general account of the electrochemical process, and protection by metal spraying and plating with specifications and tests is presented.

Application of a Systematic Scheme for Examining Corroded Metal Specimens. J. B. Cotton and R. J. Watkins. (*Corrosion Techn.*, 1957, **4**, Feb., 39–43, 74). Six examples are given of the use of a process outlined previously (*Idem.*, 1956, **3**, May, 141), one of which is a stainless steel wire mesh.

An Electrical Resistance Technique for Measuring the Corrosivity of Naphtha Streams. W. L. Terrell and W. L. Lewis. (*Corrosion*, 1956, **12**, Oct., 491–494). An accelerated laboratory test is described which enables the relative corrosiveness of different naphthas or the relative effectiveness of different inhibitors to be estimated. A thin steel shim is immersed in a sample of corrodant for about 6 h while its increase in electrical resistance due to corrosion is plotted.

Intercrystalline Susceptibility Tests on the 18/8 Group of Stainless Steels. F. Joanxich Ayma. (*Inst. de Investig. Tec. Trabajos Presentados por la Seccion de Metalurgia y Metalografia. 28th Internat. Congress of Industr. Chemistry, Barcelona*, 1956). After referring to the tendency to simplify corrosion tests, A. describes corrosion tests on Spanish and foreign stainless steels. The steels were tested in the following conditions: (1) hot rolled, descaled with final cold rolling and polishing; (2) austenitized at 1050° C for one hour and quenched in water; (3) held at 1050° C for one hour and then cooled to 700° C where it was held for one hundred hours and air cooled. The specimens were ground and polished with 0000 emery. Electrolytic polishing was carried out in a solution of phosphoric–sulphuric acid and glycerine with a current density of 0·25 amps/cm² and at 80° C. An aqueous solution of 10% oxalic was applied for 1·2 minutes at a current density of 1 amp/cm². Similar samples were also tested according to the A.S.T.M. A 262–44 T standard corrosion test. Details of the results on the four steels are given and the short time test is recommended as a corrosion test, since there is perfect agreement qualitatively between it and the standard A.S.T.M. test.—R. S.

Package Safety Test for Volatile Corrosion Inhibitors. R. K. Johnston, J. G. Schafer, and L. D. McBeth. (*PB.*111848, 1955; *TIDU List* 643, pp. 62). Tests are developed to indicate when the protection in packages drops below a safe level.

Investigation of Staining Test Methods for Evaluating Soft Film Petrolatum Type Corrosion Preventives. G. O. Wagner et al. (*PB.*116170, 1954; *TIDU List* 630, pp. 57). Three testing methods are described for long-term storage conditions. "Good" and "poor" inhibitors and emulsions were included.

ANALYSIS

Method used by the Instituto Nacional del Carbon (Oviedo) for the Determination of Phosphorus. (*Inst. Nac. Carbon Bol. Inf.*, 1956, **5**, Sept.-Oct., 223–225). [In Spanish]. The phosphorus is extracted from the coal or coke ash by treatment with a 2 : 1 mixture of nitric and hydrofluoric acids and later precipitated as ammonium phosphomolybdate. If a high arsenic content is suspected, the ash is digested with an isomolecular mixture of hydrochloric and hydrobromic acids to remove it as the volatile chloride, and the subsequent phosphomolybdate precipitation is carried out at 40° C.—P. S.

Colorimetric Determination of Iron. M. Grat-Cabanac. (*Anal. Chim. Acta*, 1957, **16**, Feb., 150). [In French]. Hypophosphite reduction is followed by reaction with 2 : 2-dipyridyl or *o*-phenanthroline.

Contribution to the Study of the Analysis of Nitrides in Steels. P. Tyou, J. Vanstiphout, and M. Lacomble. (*Rev. Univ. Min.*, 1956, 9th Series, **12**, Dec., 641–652). A review of published data on nitride analysis is first made. The properties of Al, Si, and Ti nitrides have been studied. The distribution of nitrogen between different fractions was investigated by varying the method of chemical attack.—B. G. B.

Photocolorimetric Determination of Silicon in Ferrous Metals. E. I. Fogel'son. (*Zavodskaya Laboratoriya*, 1956, **22**, (2), 163–165). [In Russian]. In the investigation described the influence of factors on the colorimetric determination of silicon was studied based on the reduction of the silicomolybdate complex by ferrous sulphate in the presence of ammonium oxalate. The factors studied include the quantity of acetate and molybdate added, the conditions for the decomposition of the yellow complex, the stability of silicomolybdate blue, and phosphoric acid content. Details are given of the procedures for cast iron, steels, and heat-resisting steels. Results for a series of irons with 1·83–4·15% Si agree satisfactorily with those of gravimetric determinations.—S. K.

New Methods of Determining Gas Contents of Steels. W. Koch. (*Berg- Hüttenmänn. Monatsh.*, 1955, **100**, July/Aug., 225–229). The theory of the solution and diffusion of gases in steel is discussed. Methods of gas analysis recently developed are described. These include a method of sampling liquid steel to collect gases evolved during solidification and apparatus for gas analysis by chemical, mass spectrograph, and spectral methods. A process of spectral gas analysis which the author has helped to develop is described. In this the spectra can be compared with absolute standards.

Separation and Determination of Microgram Amounts of Molybdenum. G. R. Waterbury and C. E. Bricker. (*Anal. Chem.*, 1957, **29**, Jan., 129–135). Separation from Fe and Pu is effected by extraction from HCl–HF with 4-methylpentan-2-one and colorimetric estimation with chloranilic acid after removal of Fe. Only Sn, W, and Bi interfere.

Colorimetric Determination of Manganese. A. R. Tourky, I. M. Issa, and I. F. Hewaidy. (*Anal. Chim. Acta*, 1957, **16**, Feb., 151–154). Precipitated MnO_2 is dissolved in alkaline tellurate solution and H_2O_2 added.

Influence of Arsenic on the Analysis of Iron and Steel. II. The Determination of Copper and Manganese in Iron and Steel. H. Gotô and S. Watanabe. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8**, June, 223–229). Mn is unaffected but Cu may require double precipitation.

Influences of Arsenic on the Analysis of Iron and Steel. III. Determination of Titanium and Molybdenum in Iron and Steel. H. Gotô and S. Watanabe. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8A**, Aug., 325–331).

Studies on the Determination of Metals by the Extraction Method with Metal Organic Compounds. XII. Determination of Molybdenum with Sodium Diethyldithiocarbamate. E. Sudo. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8A**, (5), 380–384).

On the Colorimetric Estimation of Cu, Ni, Cr and Mo in Iron and Steel. Study on the "Connective Rapid Method." H. Narikawa. (*Tetsu to Hagane*, 1956, **42**, Mar., 363–364). [In Japanese]. The method is based on the use of dimethylglyoxime, sodium diethyldithiocarbamate, diphenylcarbazide, and sodium thiocyanate. Calibration curves are given for different values of the partition volume, filter size, and absorbence cell. Results agree well with those from conventional methods for four types of steel.—K. E. J.

Rapid Photometric Methods for the Determination of Magnesium in Cast Iron. E. Zindel. (*Giesserei, Techn.-Wissensch. Beihefte*, 1956, Sept. (16), 869–874). Preliminary experiments are described in which suitable reagents and separation methods were determined. The method using hydrochloric acid is first described and a number of experimental results given. This method gives the magnesium content of iron to within ± 5% in 50–80 minutes. The second method described employs perchloric acid and gives an equal or better accuracy in 25–30 minutes.—R. J. W.

Rapid Determination of Aluminium in Iron and Steel. Y. Kakita and Y. Yokoyama. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8A**, Aug., 332–336). Photometric determination as oxinate is carried out after solvent extraction.

On the Determination of Non-metallic Inclusions in Stainless Steels by the Sulphuric Acid Method. H. Higashide. (*Tetsu to Hagane*, 1956, **42**, Mar., 368–370). [In Japanese]. A scheme is set out for determining the total of SiO_2 + (Al_2O_3 + FeO + Cr_2O_3 + MnO), and the individual amounts of FeO, Cr_2O_3, MnO, and Al_2O_3.—K. E. J.

Statistical Studies on Coal and Ore Sampling. S. Moriguchi, T. Asaka, K. Ishikawa, and T. Fujimori. (*Annual Report, Engineering Research Institute, Faculty of Engineering, University of Tokyo*, 1956, **15**, Sept., 11–17). Design of increment sampling is investigated with regard to particle size correlations.

A Study on Basicity Estimation by pH of Aqueous Extracts of Slags. K. Sawamura. (*Tetsu to Hagane*, 1956, **42**, 367–368). [In Japanese]. Details are given of pH calibrations of aqueous extracts of CaO–SiO_2 slags, and those containing 5% and 10% of MnO; 10% of FeO; and 10% of MnO, 10% of MgO and 20% of FeO.—K. E. J.

Spectrochemical Analysis of Fabricated Steel with Rotating Electrode. J. P. Pagliassotti. (*Anal. Chem.*, 1956, **28**, Nov., 1774–1776).

Flame Spectrophotometric Determination of Copper in Ferrous Alloys. J. A. Dean and J. H. Lady. (*Anal. Chem.*, 1956, **28**, Dec., 1887–1889).

Spectrographic Determination of Phosphorus in Cast Iron. L. Braicovich and M. F. Landi. (*Fonderia Ital.*, 1956, **5**, June, 213–219). [In Italian]. The authors describe a method in which they use a wave length of 830 mμ to measure the extinction of the phosphomolybdate complex and which enables them to determine the phosphorus by the analytical method proposed by Boyer. The process described is rapid and accurate and can be used also to determine the phosphorus content in carburized ferromanganese containing less than 0·35% P. (10 references).—M. D. J. B.

Operating Experience with the Spectroscopic Determination of Trace Elements and Metalloids in Pig Iron. C. Frick and K. F. Lauer. (*Arch. Eisenhüttenwesen*, 1956, **27**, Sept., 557–562). The experimental apparatus is described and effects of the shapes and nature of the samples are examined. The determination of trace elements and metalloids in solid samples is described. Spectroscopic analysis of solutions is used to determine elusive traces. Calibration procedure is discussed.—L. J. L.

Method for Local Spectrographic Analysis of Metallic Structure. Apparatus and Mg Analysis for Nodular Cast Iron. Y. Oto and T. Hamaguchi. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, July, 346–349). [In Japanese]. The method is based on the spectral lines resulting from a spark between the specimen surface and a platinum wire in a transparent quartz tube. The accuracy of 0·08 ±0·02 mm at the spark point was sufficient. In using the method for cast iron, the magnesium content of nodular graphite is taken to be greater than in the matrix; when the analysed value for magnesium (ignoring segregation) is above 0·08%, the matrix is said to contain magnesium.—K. E. J.

Accurate X-Ray Fluorescence Analysis without Internal Standard. F. Claisse. (*Province of Quebec, Dept. of Mines*, No. 327, 1956, pp. 24). Methods are given with reference to iron ores, sulphide minerals, and Nb and Ta. The matrix effect on iron determination is investigated.

X-Ray Spectrograph Eliminates Production Bottleneck. V. W. Palen. (*Iron Steel Eng.*, 1956, **33**, Dec., 151–152, 155). Analysis of leaded steel was required and was carried out in 1 hour compared with 7–8 for spectrochemical and 30–40 for gravimetric methods.

Quantometer for Steelworks Production Control. (*Iron Coal Trades Rev.*, 1956, **173**, Dec. 28, 1542). The installation of Samuel Fox and Co. is described.

Studies on Quantometer Analysis. I. Apparatus and Low Alloy Steels. Y. Oto, T. Hamaguchi, C. Matsumoto, T. Yoshinaka, and N. Nakao. (*Nippon Kinzoku Gakkai-Si*, 1955, **19**, Dec., 696–700). [In Japanese]. Initial experience with a Quantometer for analysis of Cu, Si, Mn, Cr, Ni, Mo, and V in low-alloy steels showed satisfactory results; standard deviations of 1–3% were obtained for simultaneous analyses.

Studies on Quantometer Analysis. II. Pig Irons and High-alloy Steels. Y. Oto, T. Hamaguchi, C. Matsumoto, T. Yoshinaka, and N. Nakao. (*Nippon Kinzoku Gakkai-Si*, 1955, **19**, Dec., 700–703). [In Japanese]. Satisfactory results were found for quantitative analyses of Cu, Si, Mn, Cr, and Ni in cast iron; the same elements and Mo in stainless steel; and these and W, V, and Co in high-speed steel. The instrument improves on conventional spectrographic analysis for precise estimations of Cr, Ni, W, and Co. Some effects of history of the specimen are noted for the high-speed steel.—K. E. J.

Spectrophotometric Determination of Selenium in Stainless Steels and in Copper by 3 : 3′-Diaminobenzidine. K. L. Cheng. (*Chem.-Analyst*, 1956, **45**, Sept., 67–68).

Nuclear Fission. Applications of Interest to Foundrymen and Metallurgists. (*Bradley's Magazine*, 1956, Winter, 3–4). An account of radiography using pile-activated isotopes is given.

INDUSTRIAL USES AND APPLICATIONS

New Uses for Stainless Steels. H. Biers. (*Sheet Metal Ind.*, 1957, **34**, Jan., 25–34). Uses in aircraft, automobiles, ships, reactors, architecture, and domestic equipment are briefly reviewed with notes on types and production.

Examples of Uses of Cast Steel. A. Roth. (*Z.VdI.*, 1956, **98**, Aug. 21, 1462–1468). Properties of cast and wrought steel are compared both in general terms and with reference to particular products. These include marine rudders and crankshafts, water and steam turbines, electrical machinery, and numerous other examples from heavy engineering.

Steels for Plastic-Moulding Dies. (*Tecn. Indust.*, 1956, **34**, Apr., 484–486). [In Spanish]. A review is made of the types of steels used for making moulds. Desirable properties include: easy machinability, homogeneity, ability to take a high polish, and great resistance to abrasion and deformation. Careful electric furnace steel making is preferred in order to obtain high-purity steels. Amongst those used are the carburizing steels, Cr–Ni–Mo steels for medium-size high-pressure moulds, forgings of 0·35% carbon, 0·7% chromium or 0·65% carbon steels for large moulds, and chromium stainless (0·5% C, 15% Cr, 0·25% Mo) for use with the amino-plastics. Suitable tool steels also receive a brief discussion.—P. S.

New Blading Alloy Improves Turbine Performance. P. M. Unterweiser. (*Iron Age*, 1956, **178**, Sept. 6, 100–101). The development of "Nivco" at Westinghouse Electric Corp. is described. It contains nickel, chromium, iron, and cobalt, and can be used for turbine blades at up to 1200° F.—D. L. C. P.

Ball Bearing Steel and its Importance in the Manufacture of High-quality Ball Bearings. A. Naumann. (*Technik*, 1956, **11**, Nov., 767–772). The survey is concerned principally with the heat treatment aspects of ball bearing technology. Reference is made to an automatic induction furnace for the hardening of ball races.—J. G. W.

The Properties of the Shaft Lining Rings Produced in the (Eastern) German Democratic Republic According to DIN

21501. G. Speer and H. Waldeck. (*Giessereitechn.*, 1956, **2**, Dec., 265–268). The results of tests on 1000 sample rods of 45 mm diameter and 950 mm length are reported in a series of diagrams for bending and tensile strengths, carbon, carbon and silicon, manganese, phosphorus, and sulphur contents.

Special Steels and Power Generation. Turbine Blading Conditions and Creep Research. (*Elect. Rev.*, 1957, **160**, Feb. 1, 189). In a recent lecture, Dr. Charles Sykes discussed the metallurgist's contributions to electric power generation. Increases in steam temperatures in generating plant have led to the use of 2¼% Cr–Mo steel for 1000° and 2¼% Mo and V at 1050° F. As temperatures increase further the use of austenitic steels will become more general. Problems raised by corrosion resistance, variable pressures, and the effect of temperature on creep properties were discussed in relation to the composition of turbine blading, and the design of rotor shafts with regard to high and low temperatures and pressures was dealt with. Future trends in materials and design were indicated.—L. D. H.

Spring Materials for High Temperature Service. (*Product Eng.*, 1956, **27**, Aug., 186–193). For springs in service in corrosive or high temperature conditions special steels are required and a comparison is given of the suitability of a number of typical materials. The allowable design stresses for springs at high temperatures and for different duties are discussed and details are given of the properties of a number of suitable steels.—E. A. C.

Steels and Alloys for Permanent Magnets. L. Dainelli. (*Rivista Mecc.*, 1956, **7**, May 12, 7–13). [In Italian]. A detailed review is given of the various steels which are suitable for permanent magnets, their chemical composition, heat treatment, and magnetic properties are listed and discussed.

Stainless in Aircraft Design. (*Steel*, 1956, **139**, Nov. 12, 152–154). Data on the properties of martensitic types of stainless steels for aircraft parts are given. The effects of temperature on strength are noted, and heat treatments are considered.—D. L. C. P.

The Use of Alloy Cast Irons for the Construction of Chemical Plant. E. Rabald. (*Werkstoffe Korrosion*, 1956, **7**, Aug.-Sept., 435–448). A well-documented survey of practical applications in the chemical industry of low- and high-alloy cast irons containing Cr, Ni, Si, and Mo, alone or in various combinations. Numerous examples are given of components made from these materials.—J. C. H.

Considerations Affecting Future Pressure-Vessel Codes. J. J. Murphy, C. R. Soderberg Jun., and D. B. Rossheim. (*Welding J.*, 1956, **35**, Dec., 582s–595s). The authors indicate tentative basic principles for revision of the ASME pressure-vessel codes to a broader base to suit the wide variations in service and economic demands.—U. E.

Turbine Disks for Jet Propulsion Units. A. E. Johnson. (*Aircraft Eng.*, 1956, **28**, June, 187–195; July, 236–243; Aug., 265–272; Sept., 325–332; Oct., 348–356). An account of the work of the Disk Panel of the M. of S. Gas Turbine Collaboration Committee 1941–1949 is presented. The first part deals with stress calculations and selection of materials. Fixings are then reviewed and tensile creep and auxiliary creep tests and illustrations of fractures given. Equations for stress and plastic strain for isotropic materials are advanced and conclusions and recommendations are summarized at the end. Many tables and diagrams are included.

On the Adaption of Materials for Use in Rocket Motors. J. Venturini. (*Métaux–Corrosion–Indust.*, 1956, **31**, July-Aug., 311–336). A detailed consideration is made of materials suitable for use in rocket motors. Among the materials studied are alloy steels.—B. G. B.

Metallurgy in the Nuclear Power Industry. W. E. Dennis. (*Metallurgia*, 1957, **55**, Jan., 23–26). A review of metallurgical aspects of nuclear power production is presented.—B. G. B.

Low Manganese Steels for Nuclear Applications. H. F. Beeghly. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Dec., 1664–1670). For applications where sources of radioactive isotopes must be kept to a minimum, steels with low manganese contents are desirable. Steels with 0·10–0·15% Mn have been made by the basic O.H. process, rolled into plate, bar, and seamless tubing, and found to be interchangeable with standard steel grades for many uses. They show superiority to standard grades in freedom from strain ageing, improved high temperature strength and ductility, and absence of certain disadvantageous nuclear and chemical properties. The manganese was replaced by titanium or zirconium with aluminium.—G. F.

HISTORICAL

Ancient Metallurgy. L. Cambi. (*Atti Accad. Lincei*, 1956, **5**, (11), 619–629). A brief historical account of early centres of the art, with special reference to iron.

The Position of Excavations Relating to the Ancient Production of Iron in Czechoslovakia and Other Slav Countries. R. Pleiner. (*Techn. Civil.*, 1956, **5**, (4), 113–128). An illustrated account of furnaces, forges, etc. excavated in Czechoslovakia, Poland, and the U.S.S.R. in recent years with analyses of slags and examinations of iron and steel objects divided into the four cultures, Hallstatt, La Tène, Roman Age, and Slav Age, with reconstructions and discussion.

Early Refining of Pig Iron in England. H. R. Schubert. (*Trans. Newcomen Soc.*, 1951–1952 and 1952–1953, **28**, 59–75). The finery hearths and process are described.

Early Ironfounding in the Midlands. W. K. V. Gale. (*Trans. Newcomen Soc.*, 1951–1952 and 1952–1953, **28**, 225–231).

The Earl of Dudley's Level New Furnaces. T. M. Hoskinson. (*Trans. Newcomen Soc.*, 1951–1952 and 1952–1953, **28**, 153–161). Early history of the Brierley Hill ironworks, South Staffordshire, is given.

Sources for the History of the Swiss Iron Industry and the Swiss Iron Trade. The Diary of Bernhard Neher. K. Schib. (*Nachrichten Eisen-Bib. Georg Fischer A.G.*, 1956, Nov. reprint). B. Neher (1814–1865) was the son of J. G. Neher who founded an iron works at Schaffhausen in 1809.

Stages in the Development of Industrial Metallurgy. F. T. M. White. (*Australasian Eng.*, 1956, **48**, Oct. 8, 43–53). An historical account of metallurgy, mainly non-ferrous, from the earliest times, with notes on the guild system and on present-day training facilities and laboratories.

The Centenary of the Bessemer Process. H. Schmidt. (*Giesserei*, 1956, **43**, Nov. 22, 791–792). A short article to mark the centenary of the Bessemer process. The development of the process from the first patent taken out by Henry Bessemer in 1855 to the present century is described. Diagrams from the original patent are reproduced, together with some of more recent converters.—R. J. W.

Origins of the Open-Hearth Furnace. First Patents Now Just Over 100 Years Old. (*Iron Coal Trades Rev.*, 1957, **174**, Jan. 25, 207–210). Brief accounts of F. and W. Siemens and P. Martin.

Regenerative Furnaces. Centenary of Sir William Siemens' Patent. M. Schofield. (*Iron Steel*, 1957, **30**, Feb., 44, 68).

The Brothers Friedrich and Wilhelm Siemens: The Inventors of the Regenerative Furnace. Centenary of the Patent Application on Dec. 2, 1856. H. J. van den Berg. (*Stahl u. Eisen*, 1956, **76**, Nov. 29, 1612–1615). An historical note.—T. G.

George James Snelus. E. N. Simons. (*Metallurgia*, 1957, **55**, Jan., 8–10). A biographical note of the metallurgical activities of Snelus is presented.—B. G. B.

ECONOMICS AND STATISTICS

Iron and Steel Industries of the World. II—Markets and Consumption. (*Financial Times Survey*, [1957], 33).

Molybdenum and Vanadium. (*Financial Times Survey*, [1957], 46). Reserves, producers, stocks, and consumption are briefly reviewed.

MISCELLANEOUS

The Metallurgist's Place in Production Engineering. A. J. Kemp. (*Australian Mach. Prod. Eng.*, 1956, **9**, July, 15–17, 19, 21, 23). The academic training of metallurgists in the Commonwealth is outlined and the metallurgical aspects of product design, material specification, mechanical working, heat treatment, surface finishing, and product testing are discussed.—A. W. McC.

The Oxidation of Magnetite and Related Spinels. Constitution of Gamma Ferric Oxide. I. David and A. J. E. Welch. (*Trans. Faraday Soc.*, 1956, **52**, Dec., 1642–1650).

Ion-exchange Methods and their Application to Metallurgical Problems. C. B. Amphlett. (*Met. Rev.*, 1956, **1**, (4), 419–473). A general review. References to ferrous metallurgy are few.

An Iron-rich Wagnerite, formerly named Talktriplite, from Hållsjoberget (Horrsöjberget), Sweden. A. Henriques. (*Arkiv Min. Geol.*, 1957, **2**, 149–153).

ANDREWS, C. REGINALD: "*The Story of Wortley Ironworks.*" Second Edition (enlarged and revised), edited by Mary Andrews. 8vo, pp. [xv +] 98. Illustrated. Nottingham, 1956: R. Milward and Sons, Ltd. (Price: unbound 7*s.* 6*d.*; cloth bound 15*s.*).

Since the original publication of the late Rev. C. R. Andrews' book (reviewed in the *Journal* for March, 1951, p. 350), the hoped-for restoration of the Wortley Top Forge has been accomplished; scheduled as an Ancient Monument, it is now under the care of the Friends of Wortley Society, and in this new edition Miss Mary Andrews includes an account of the Reopening Day on July 9th, 1955. A considerable amount of other new material has been inserted and the number of illustrations more than doubled, a most interesting addition being the reproduction of parts of a map of the Wortley mills and forges, drawn in 1746.

Much fresh information has recently come to light among the Earl of Wharncliffe's archives and other papers in the Sheffield City Library relating to the proprietorship of Wortley Ironworks in the seventeenth century, and the whole question is examined afresh by Mr. and Miss Andrews —though, as the former indicates, further research is needed to clear up obscurities which still remain. It is much to be hoped that this will be carried out, so that in due course a further edition may enhance still more the value of this attractive and well-produced history.—A. E. G. WRIGHT.

HARMAN, C. ROWLAND (Editor). "Handbook for Welding Design." Volume I. 8vo, pp. xvi + 305. Illustrated. London, 1956: Sir Isaac Pitman and Sons, Ltd., for the Institute of Welding. (Price 45*s.*).

The rapid expansion of the application of metal-arc welding to various metals and alloys has naturally stimulated the publication of vast numbers of scientific and technical papers together with specifications, rules, and regulations. It is not surprising, therefore, that the Institute of Welding has found it necessary to supersede its "Handbook for Welded Structural Steelwork" by a manual of wider scope covering the latest British practice of using metal-arc welding in engineering design and construction.

The first volume of the new manual is welcomed with pleasure; its aim is to provide the designer with the fundamental data necessary to design a welded assembly or structure of the required standard of quality and with an eye on economy; the materials considered are limited to mild and low-alloy steels. Volumes II and III will be concerned with the application of the data given in the present volume to typical examples from plant and structural engineering.

After a brief introduction to the principles of the arc welding process, three chapters are devoted to the selection of materials, basis metal, section data and electrodes. In Chapter 2 the designer is given guidance on the mechanical properties and weldability of steels. Such items as "controlled thermal severity tests" and notch-brittleness are treated with considerable brevity, but a list of references to original papers is given at the end of the chapter. Chapter 3 consists of data on the dimensions and properties of British rolled sections together with built-up sections fabricated by welding. This chapter is printed on blue paper which assists easy ready reference to it. Chapter 4 deals with the classification of electrodes and is merely a summary of the relevant B.S. Specifications.

The next three chapters cover the design and application of welded joints. Recommended forms of joint in the assembly of plates, sections, and tubes are given in Chapter 5, while Chapter 6 deals with the loading conditions and sets out the working stresses specified for each group. It is gratifying to note that the importance of fatigue stresses is adequately brought out. Numerous worked examples are given of the design of typical connections, and the use of these various joints in typical assemblies is discussed in Chapter 7. A final chapter considers the factors influencing welding costs.

The volume is nicely printed and well illustrated, and, although one is tempted to ask for a more comprehensive treatment of some aspects of the subject, the book, even in its present form, will be of great value to designers approaching the subject for the first time and also to lecturers and students.—E. C. ROLLASON.

CLARK, M. GARDNER. "*The Economics of Soviet Steel.*" (Russian Research Center Studies: No. 25). La. 8vo, pp. xvi + 400. With map and two charts. Cambridge, Pa., 1956: Harvard University Press. (Price 60*s.*).

This critical assessment of information from Soviet sources traces the industry's growth through the inter-war period of indiscriminate copying of large U.S. plants ("gigantomania") to the present rationalized growth within the limitations imposed by the raw-materials outlook (worsening quality and increasing shortage of both coking coal and iron ore). Although the 1940 shift eastwards turned out to be mainly a statistical one (increased productivity of plant and equipment installed there during the 1930's being the real reason), nevertheless the raw materials question may eventually necessitate a very real move even farther east than the Urals or the Kuznetsk Basin, which have their own individual problems to solve. In any case, continued expansion of Soviet steel production at the recent high rate of 3–4 million tons per annum will be possible only if there is a big improvement in the flagging rate of capital investment; and, although the U.S.S.R. is well supplied with labour, capital is in short supply. "A cut in consumption of steel by armaments would help to avoid some of the technical and investment problems associated with further growth, and we have a strong suspicion that the leaders responsible for the expansion of Soviet iron and steel would welcome such a reprieve."—E. BREWIN.

DE CARLI, FELICE. "*Vita dei Metalli.*" (Il Prisma: Collana di Divulgazione Scientifica Diretta da Gaetano Castelfranchi, 5). 8vo, pp. xiii + 269. Illustrated. Milan, 1956: Casa Editrice Dr. Francesco Vallardi.

This is a story—the story of metals—the story of the part they have played from the bronze and iron ages to this day; of the way in which they have influenced the course of civilization, of how they have affected art, politics, and religion. The alchemists of Ancient Egypt, of early christianity and of the middle ages were gradually displaced by a new thinking and by the new man of the renaissance. Superstition gave way to science and alchemy to chemistry. Iron nails and gold vessels are both of metal, both in their respective ways are necessary to man and both are discussed in the book.

"*Vita dei Metalli*" is not a technical work. This is not meant pejoratively—quite the reverse. It is a fascinating account of the impact of metals on mankind. There is food for thought in the author's philosophical approach to the subject and in his way of explaining the development of metallurgy by man's ability to produce heat—new ways of getting higher temperatures have led to better ways of making the known metals and have shown the way to new ones.

No educated person today, whatever his interests, can be totally ignorant of the metals which make modern life. This book will appeal to a wide reading public. To the non-technical person it will give an insight to the world of metals, their discovery, manufacture, and uses. To the technical expert it will help give an historical and cultural background to the metals he is familiar with. The book has a number of excellent plate illustrations.—M. D. J. BRISBY.

NOTE

"*Réaumur's Memoirs on Steel and Iron.*" A translation from the Original by Anneliese Grünhaldt Sisco. (*See* this *Journal*, 1957, May, p. 151). We are asked to state that this book is also published in the United Kingdom by the Cambridge University Press, price 45*s.*

AMERICAN FOUNDRYMEN'S SOCIETY. "*Foundry Air Pollution Control Manual.*" Folio, pp. v + 58. Illustrated. Des Plaines, Ill., 1956: The Society. (Price 43*s.*).

AMERICAN SOCIETY FOR TESTING MATERIALS. "1956 *Book of ASTM Methods for Chemical Analysis of Metals.*" (A Part of the Book of ASTM Standards). 8vo, pp. x + 627. Illustrated. Philadelphia, Pa., 1956: The Society. (Price $8.00).

AMERICAN SOCIETY FOR TESTING MATERIALS. "1956 *Supplement to Book of ASTM Standards Including Tentatives.*" Part 2. "*Non-Ferrous Metals.*" 8vo, pp. xv + 335. Illustrated. Philadelphia, Pa., 1956: The Society.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on pH Measurement.*" Presented at the Fifty-Ninth Annual Meeting, American Society for Testing Materials, Atlantic City, N.J., June 19, 1956. 8vo, pp. v + 101. Illustrated. Philadelphia, Pa., 1957: The Society. (Price $2.50).

"*Automation in the Iron and Steel Industry.*" Proceedings of the Fourth and Fifth Annual Conferences on Instrumentation for the Iron and Steel Industry, 1954 and 1955, sponsored by the Pittsburgh Section of the Instrument Society of America. Folio, pp. 98. Illustrated. Pittsburgh, Pa., 1956: The Instruments Publishing Co. (Price 18*s.*).

BASHFORTH, G. REGINALD. "*The Manufacture of Iron and Steel.*" Volume One. "*Iron Production.*" Second edition, revised. 8vo, pp. xi + 306. Illustrated. London, 1957: Chapman and Hall Ltd. (Price 45*s.*).

BORCHERS, HEINZ. "*Metallkunde.*" I. "*Aufbau der Metalle und Legierungen.*" (Sammlung Göschen, Band 432). Dritte Auflage. Sma. 8vo, pp. 120. Illustrated. Berlin, 1956: Walter de Gruyter and Co. (Price DM. 2.40).

BORRIES, BODO VON; HANS HEINRICH EMSCHERMANN; KARL ERICH HEINERTH, und BERTHOLD SCHEDA. "*Elektonische Mess- und Steuergeräte in U.S.A.*" (Reisebericht einer deutschen Studiengruppe). Pp. 41, illustrated. München, 1956: Hanser. (Price DM. 4.60).

BRITISH STANDARDS INSTITUTION. B.S. 1016: Part 1: 1957. "*Methods for the Analysis and Testing of Coal and Coke.*" *Part* 1. "*Total Moisture in Coal.*" 8vo, pp. 15. Illustrated. London, 1957: The Institution. (Price 3*s.* 6*d.*).

BRITISH STANDARDS INSTITUTION. B.S. 2772: Part 3: 1957. "*Iron and Steel for Colliery Haulage and Winding Equipment.*" 8vo, pp. 12. Illustrated. London, 1957: The Institution. (Price 3*s.*).

BÜCHNER, HERMANN. "*Moderne Metallbearbeitung.*" 4to, pp. 288. Illustrated. München, 1956: Carl Hanser Verlag. (Price DM. 48.–).

ČS. VĚDECKÁ TECHNICKÁ SPOLEČNOST PRO HUTNICTVÍ A SLÉVÁRENSTVÍ PŘI ČSAV; VÝZKUMNÝ ÚSTAV MATERIÁLU A TECHNOLOGIE, PRAHA. "*Sbornik Defektoskopie.*" [Papers on Defectoscopy]. Lectures at a Meeting on Non-destructive Testing, Brno, 1st and 2nd March, 1956. 8vo, pp. [iv +] 358. Illustrated. Praha, 1956: Matice Hornicko-Hutnická.

"*Forgemaster's Meeting* 1954." The Iron and Steel Institute, Special Report, No. 60. La. 8vo, pp. viii + 92. Illustrated. London, 1957: The Institute. (Price 37*s.* 6*d.*; [Members 25*s.*]).

GARSIDE, JAMES E. "*Process and Physical Metallurgy.*" Second edition, revised. 8vo, pp. xx + 593. Illustrated. London, 1957: Charles Griffin and Co., Ltd. (Price 54*s.*).

"*Die Giesserei- und Metallindustrie der Schweiz.*" Im Einvernehmen mit dem Verband Schweizerischer Eisengiessereien, Zurich, und Verband Schweizerischer Metallgiessereien, Bern. 8vo, pp. 152. Zürich, 1957: Verlag für Wirtschaftsliteratur. (Price DM. 15.–).

GUINIER, A. "*Théorie et Technique de la Radiocristallographie.*" 2e édition. La. 8vo, pp. xviii + 736. Illustrated. Paris, 1956: Dunod. (Price 9,500 fr.).

"*Jahrbuch der Oberflächentechnik.*" 13th Edition. 8vo, pp. 1130. Illustrated. Berlin-Grunewald, 1957: Metall-Verlag. (Price DM. 19.50).

KREKELER, K. "*Das Verbinden von Metallen durch Kunstharzkleber.*" Teil 1. "*Eigenschaften und Verwendung der Metallklebstoffe.*" (Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen, No. 245). 4to, pp. 38. Illustrated. Köln und Opladen, 1956: Westdeutscher Verlag.

LAUGHNER, VALLORY H., and AUGUSTUS D. HARGAN. "*Handbook of Fastening and Joining of Metal Parts.*" First edition. La. 4to, pp. ix + 622. Illustrated. New York, Toronto, London, 1956: McGraw-Hill Book Co., Inc. [Price 112*s.* 6*d.*).

LEONHARD, A. "*Die selbsttätige Regelung.*" Theoretische Grundlagen mit practischen Beispielen. 2. neue Auflage. 8vo, pp. xii + 376. Illustrated. Berlin (etc.), 1957: Springer-Verlag. (Price DM. 39.–).

LINDORF, H. "*Technische Temperaturmessungen.*" 2. Auflage. (Fachbücher für Ingenieure). 8vo, pp. 243. Illustrated. Essen, 1956: W. Girardet. (Price, DM. 19.80).

MINCHINTON, W. E. "*The British Tinplate Industry.*" A History. 8vo, pp. xviii + 286. Illustrated. Oxford, 1957: Oxford University Press. (Price 35*s.*).

PELOU, MAURICE. "*Les Aciers de Fabrication Française.*" 6e Edition. Revue et mise à jour. 4to, pp. 156 + xvi. Paris, 1956: Science et Industrie. (Price 5150 Fr.).

"*Problémy a Výhledy Našeho Hutnictví a Slévárenství.*" Sborník prací k sedmdesátým narozeninám akademika Františka Píška. ["*Problems and Outlook of the Czechoslovak Metallurgical and Foundry Industries.*" Dedicated to Prof. F. Pišek, Member of the Czechoslovak Academy of Science, in honour of his seventieth birthday]. La. 8vo, pp. 479. Illustrated. Prague, 1956: State Publishers of Technical Literature.

PUZAK, P. P., and H. RISCHALL. "*Further Studies on Stainless-Steel Hot Cracking.*" (Naval Research Laboratory, Washington, NRL Report 4861.) La. 4to, pp. ii + 10. Illustrated. Washington, D.C., 1956: Naval Research Laboratory.

ROBERTSON, WILLIAM D. (Editor). "*Stress Corrosion Cracking and Embrittlement.*" A Symposium Arranged by the Corrosion Division of the Electrochemical Society, Boston, October, 1954. 8vo, pp. viii + 202. Illustrated. New York, 1956: John Wiley and Sons, Inc.; London, Chapman and Hall, Ltd. (Price $7.50).

ROSS, R. (General Editor). "*Proceedings of the Third International Conference on Electron Microscopy.*" 4to, pp. xv + 705. Illustrated. London, 1956: The Royal Microscopical Society. (Price 90*s.*).

SCOTT, W. H., J. A. BANKS, A. H. HALSEY, and T. LUPTON. "*Technical Change and Industrial Relations.*" A Study of the Relations between Technical Change and the Social Structure of a Large Steelworks. (The University of Liverpool, Department of Social Science). 8vo, pp. [xi +] 336. Illustrated. Liverpool, 1956: Liverpool University Press. (Price 17*s.* 6*d.*).

SMITH, MORTON C. "*Alloy Series in Physical Metallurgy.*" 8vo, pp. xi + 338. Illustrated. New York, 1956: Harper and Brothers, Publishers. (Price 50*s.*).

SMITH, MORTON C. "*Principles of Physical Metallurgy.*" 8vo, pp. xiii + 417. Illustrated. New York, 1956: Harper and Brothers, Publishers. (Price 50*s.*).

SWAINGER, KEITH. "*Analysis of Deformation.*" Volume Three. "*Fluidity.*" 8vo, pp. xxvii + 266. Illustrated. London, 1956: Chapman and Hall Ltd. (Price 65*s.*).

VÝZKUMNÝ ÚSTAV MATERIÁLU A TECHNOLOGIE. "*Materiálový Sborník* 1956." [Reports on Materials 1956]. 8vo, pp. 192. Illustrated. Praha, 1956: Matice Hornicko-Hutnická.

WARBURTON-BROWN, D. "*Induction Heating Practice.*" A Handbook on the High-Frequency Induction Process for All Concerned with Engineering Production. 8vo, pp. 192. Illustrated. London, 1956: Odhams Press, Ltd. (Price 21*s.*).

WHITE, C. LANGDON. "*Is the West Making the Grade in the Steel Industry?*" (Business Research Series No. 8). 8vo, pp. v + 24. Illustrated. Stanford, California, 1956: Graduate School of Business, Stanford University. (Price 75 cents).

WITTHOFF, J. "*Der kalkulatorische Verfahrensvergleich, insbesondere die Wirtschaftlichkeitsrechnung.*" (Das Rifa-Buch, Vol. 5). 8vo, pp. 182. München, 1956: Hanser. (Price DM. 17.80).

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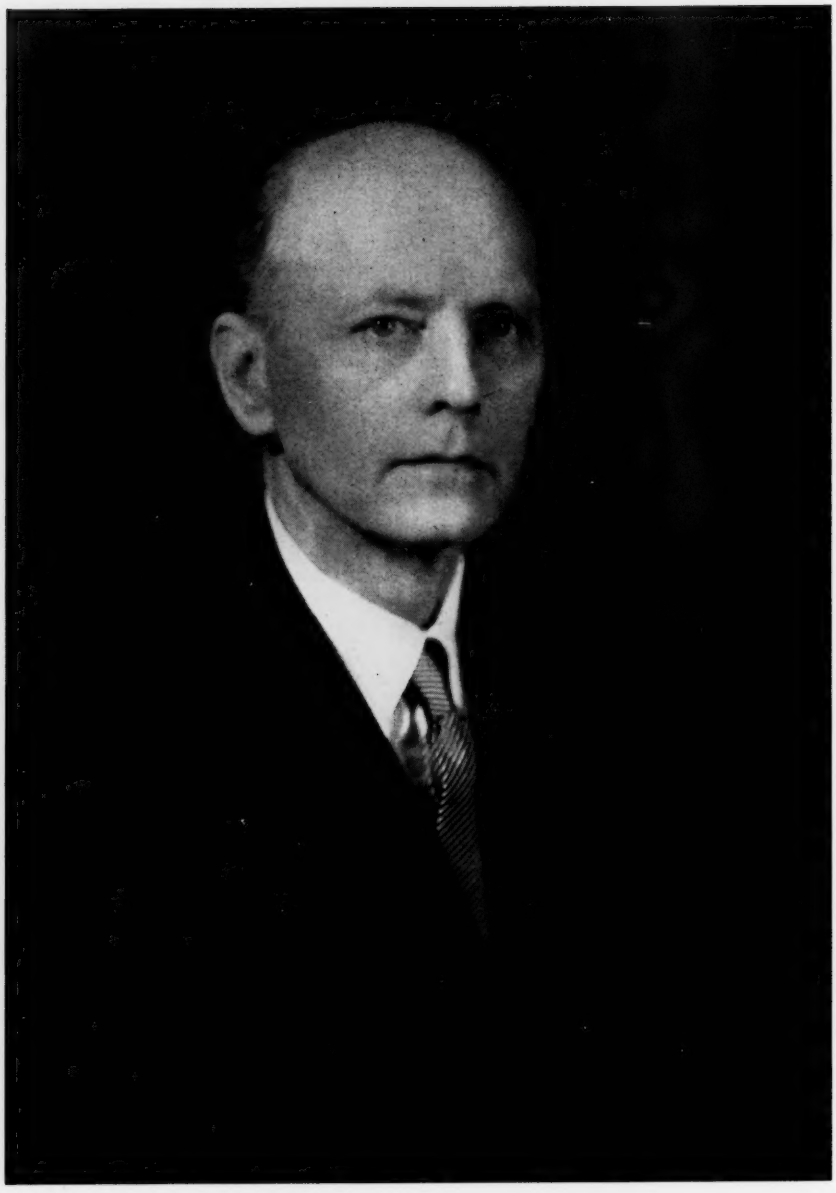

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